THE
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ADVANCED CONTROL AND DISPLAY TECHNIQUES AND APPLICATION STUDY

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ADVANCED CONTROL AND DISPLAY TECHNIQUES AND APPLICATIONS STUDY

REVIEW OF CONTROL AND DISPLAY COMPONENTS DEFINING INTERFACE, THERMAL, ILLUMINATION AND POWER REQUIREMENTS

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FOREWORD

This report, submitted by The Bendix Corporation, Navigation and Control Division to the Marshall Space Flight Center, Huntsville, Alabama, is in response to Contract NAS8-28657, Tasks 3 and 4.

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SECTION 1

INTRODUCTION

This study program entitled, "Advanced Control and Display Techniques and Applications" has as an objective the definition of a family of Controls and Displays (C and D) with improved flexibility, reliability, and redundancy as compared to existing displays to meet the demands of long duration space flights.

Dramatic advances have been made in recent years in the C and D field particularly in the display area. Even as this report was being prepared new information became available almost daily making it difficult to establish a cut off date for the reporting of tasks 3 and 4. Specific display technologies, as well as techniques of integration and/or interaction with digital computers, are progressing at a rapid rate. Order of magnitude reductions have been made in power requirements.

It is readily apparent that devices available for installation in the next generation of spacecraft will exhibit vast improvements in reliability, functional redundancy, and flexibility.

SECTION 2

DISCUSSION OF TASKS

During the initial stages of this phase of the Advanced Control and Display Techniques and Applications Study it was determined that interfacing with a data management subsystem (DMS) and an onboard checkout subsystem (OCS) would normally take place at the C and D Panel level of the system hierachy and not at the individual device level. To establish the interface with the DMS and OCS would require a thorough definition of the specific application, mission, etc. and the DMS and OCS to be implemented.

It was considered appropriate, as a step ultimately leading toward that goal, to survey and define the characteristics and requirements at the C and D device level since this is a necessary step in the definition of a complete C and D station. The work content of tasks 3 and 4 has been performed based upon this philosophy.

SECTION 3

SUMMARY

This report describes a wide variety of visual devices considered potential candidates for installation in manned space vehicles and capable of displaying the necessary information for status reporting, experimental data collection and vehicle control. Both alphanumeric and graphical type devices are covered incorporating the technologies of light emitting diodes, liquid crystals, gas discharge , electroluminescence, cathode ray tubes, and incandescent projection. Where considered appropriate comparisons of performance parameters of the various types in a particular category have been made, with the results presented in chart form.

The devices described and compared fit into three general categories i.e., alphanumeric readouts, message indicators, and random access displays. Although the categories overlap, in some cases extensively, the following definitions apply.

An alphanumeric readout provides the capability of generating any alphanumeric (and a limited number of symbols i.e. +, -, ., etc.) in several fixed locations. In the majority of applications this amounts to a 3 to 8 digit readout. However, as described in the text, special devices have been built to display as many as 512 digits on a single panel. Normally these latter devices are used as alphanumeric data terminals for interactive communication with a computer.

A message indicator is a device capable of displaying unvarying, fixed messages consisting of alphanumeric and/or pictorial information usually within a very limited area. Devices capable of displaying up to 64 such messages are available and may be a cost effective solution to a specific requirement where complete flexibility is not necessary. Both incandescent and CRT versions of this type indicator are available.

A random access display is defined as one allowing complete freedom to generate spots, lines, alphanumerics, graphics, etc. anywhere on the display area. The device most obvious and having the longest history for this purpose is the conventional CRT. However, there are currently two relatively new flat panel devices that perform this function, both of which are described and compared in this report. One operates utilizing the gas discharge principle and the second is a digitally addressed CRT.

SECTION 4

SOLID STATE DEVICES

The following state of the art solid state devices are examined in depth for the purpose of delineating salient technical principles, operating characteristics, and general application to spacecraft equipment:

a) Light Emitting Diode Devices

b) Liquid Crystal Devices

c) Plasma, or Gas Discharge, Devices

d) Electroluminescent Devices

4.1 Light Emitting Diodes

4.1.1 General Principles

The physical properties and operating principles of light emitting diode (LED) devices are intricately detailed in an abundance of research literature. It is not considered to be within the scope of this report to dwell on the enumeration of solid state principles, therefore, only a synopsis is provided to familiarize the reader with the general technology. The reader is directed to the bibliography if a more exhaustive investigation is warranted.

LEDs can be operationally defined as devices designed to efficiently convert electrical energy into electromagnetic radiation, most of which is perceptible to the human eye. In essence, the device is a p-n junction diode that emits visible or infrared radiation when biased in a forward direction. Luminescence arises from a two-step process in which electrons and holes are generated in concentrations greater than those permitted at thermal equilibrium, and then a significant fraction of these carriers recombine. Radiative recombination occurs when the energy of the recombining holes and electrons generates photons.

The recombination process is nearly independent of the source of the excess carriers but is strongly characteristic of the physical and electrical properties of the LED compound. The recombination of the excess minority carriers within a specified length of the junction is the mechanism by which electroluminescence is generated.

Three principal semiconductor compounds are presently used to construct LED devices; gallium arsenide phosphide (GaAsP), gallium phosphide (GaP), and gallium arsenide (GaAs). Gallium arsenide emits infrared radiation in the 0.9 millimicron region and thus is not, technically, considered light. Exact wavelength is determined by doping the various compounds with such dopants as Zn, Cu, O, N, and Te.

Figure 4.1 shows the emission characteristics of these LED semiconductors. The responses shown are relative to the maximum sensitivity of the normal eye. The current technology limits LED color selection primarily to red and green, with red being much more advanced in its technology.

The most popular LED compound is GaAsP although some manufacturers argue a strong case for GaP. GaAsP emits light over a red-orange spectrum ranging from 0.64 to 0.7 millimicrons. By increasing the GaP percentage, light can be attained at shorter wavelengths, thereby producing orange emission but at reduced efficiency of the diode in converting electricity to light. Amber colored GaAsP LEDs are currently available from a small number of manufacturers. The average efficiency of the red GaAsP diode ranges from about 0.2 to 0.5 percent depending, in part, on the method of encapsulation.

GaP emits red light between 0.63 and 0.75 millimicrons. The diode can also emit green light at wavelengths between 0.5 and 0.47 micrometers with an intensity peak around 0.5 millimicrons, which is close to maximum eye sensitivity.

Green-emitting GaP diodes are still in their infancy but are commercially available from a limited number of vendors. The efficiency of green GaP ranges from 0.01 to 0.06 percent.

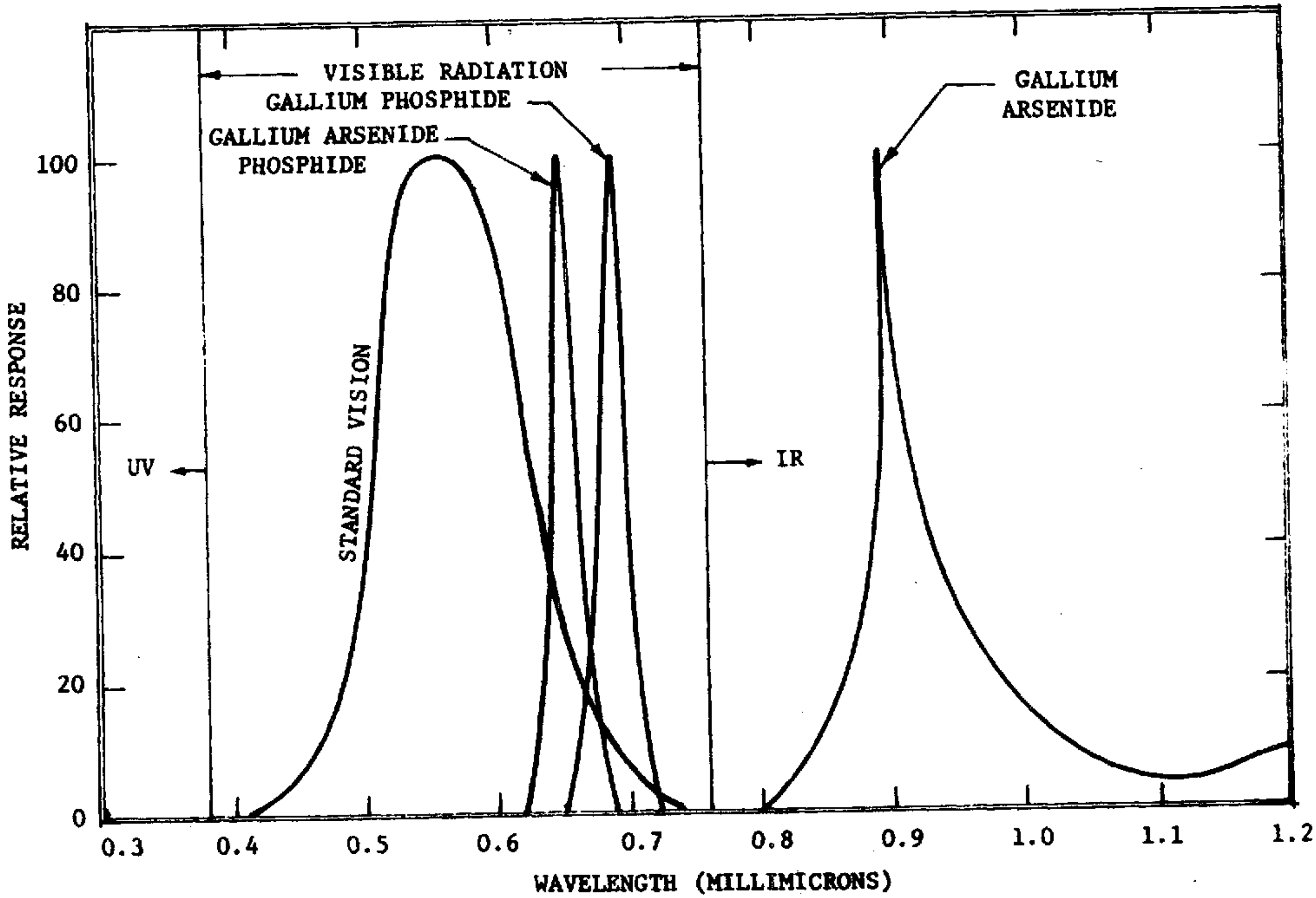


FIGURE 4.1 SPECTRAL RESPONSE CURVES

It is also reported that orange or yellow emissions are obtainable from GaP diodes. Since green emission arises predominantly from the n-side and red emission from the p-side of the junction, the one diode emits both colors simultaneously, whereas the eye integrates the sensations into a single orange or yellow appearance.

Although the efficiency of the diode decreases as the wavelength becomes shorter, the eye, in part, compensates for this condition since the visual mechanism functions with increased luminous efficiency in the shorter wavelengths. Thus, the eye responds nearly as well to the green emitters as to the red emitters even though the red is approximately 35 times more efficient in terms of lumens per watt emitted as measured against watts of power dissipated. Some typical efficiencies quoted by manufacturers and the resulting overall luminous efficiency (lumens per watt) are listed:

a) GaP (red):

1) Efficiency: 0.72% at 20 lumens per watt

2) Luminance: 0.14 lumens per watt (overall)

3) Manufacturer: Opcoa

b) GaP (green):

1) Efficiency 0.006% at 657 lumens per watt

2) Luminance: 0.04 lumens per watt (overall)

3) Manufacturer: Monsanto

c) GaAsP (red):

1) Efficiency: 0.3% at 50 lumens per watt

2) Luminance: 0.15 lumens per watt (overall)

3) Manufacturer: Litronix

d) GaAsP (amber):

1) Efficiency: 0.0044% at 340 lumens per watt

2) Luminance: 0.015 lumens per watt (overall)

3) Manufacturer: Monsanto

All efficient LEDs are located on the extreme red to green region of the spectrum. Silicon carbide and GaAs with converter phosphers produce blue light, however, the efficiency of both devices is low by 1 to 3 orders of magnitude compared with the diodes emitting the red to green.

4.1.2 Categories

LED devices presently in production can be grouped in the following categories:

a) Single-diode, visible-light emitters for panel lamps and indicators.

b) Arrays of diodes for numeric and alpha-numeric presentations. (Dot matrix or segments)

c) Infrared emitting diodes that are nonlasing for industrial controls.

d) Single infrared-emitting laser diodes and arrays for high-power radiation, laser ranging, and gated viewing systems.

4.1.3 Performance Specifications

Table 4.1 presents representative specification data for visible LED devices.

4.1.4 Salient Design Problems

Major device-related design problems include:

a) Low luminous efficiency.

b) Red LEDs emitting in the .7-millimicron region of the spectrum, have poor visual discrimination for a significant segment of the user population.

c) High materials costs.

TABLE 4.1

Typical LED Performance Specifications

Supply Voltage	2 to 5 VDC
Drive Frequency	DC, pulse stroked
Current	15 to 30 milliamperes per segment
Capacitance	25 picofarads per segment
Operating Temperature	-55^{o} to $+85^{o}C$
Storage Temperature	-40^{o} to $+100^{o}C$
Brightness	200 to 5,000 ft. l.
Rise and Fall Time	1 to 50 nanoseconds
Life	1,000,000 hours
Mean Time Between Failure (MTBF)	100,000 hours
Vibration	MIL STD 883
Shock	1,500 g: X,Y, & Z planes
Color	Red, green, orange
Packaging	Several configurations available: Dual inline plastic (DIP), ceramic, flat pack, etc. (Hewlett Packard has put a 7 x 4 matrix and a decoder or control latch into a single package).

4.1.5 Design Advantages

LED devices have been commercially available only for approximately 3 years, however, during that period they have achieved widespread acceptance in a vast array of display system applications. This acceptance trend has progressed because of the technology's rapid increase in efficiency coupled with a rapid decrease in cost. Efficiency and cost have changed by a factor of 20 with overall unit reliability upgraded by almost 5 orders of magnitude.

The major design advantages germane to a spacecraft application are:

a) Safety - No filament elements, non toxic material.

b) Low Voltage

c) Flexibility - Individual lamps, fixed format, numeric 7-bar or 3 x 5 array, alphanumeric 5 x 7 dot array.

d) Circuit Compatibility - Compatible with low power integrated circuits (can be driven directly by RTL, DTL, and TTL logic). Allows vertical compatibility with existing semiconductor technology.

e) Panel Area - Allows installation in small panel space, monolithic construction.

f) Brightness Variation - Provided either by altering the current or pulsing (variable duty cycle).

g) Speed - Less than 1 microsecond.

h) High Vibration Tolerance

i) Reliability - The LED is potentially the most reliable light source based on the physical properties of its operation and probable modes of failure. Due to the recent availability of the device, an extensive amount of reliability testing has not been performed to date, however, reliability should approximate that of other semiconductor diodes.

The present estimate of LED operating life is based upon the useful life definition of light output decreasing to 50% of the original brightness. Accelerated testing has placed this point well in excess of 100,000 hours with some manufacturers advocating upwards to 1,000,000 hours. In addition, as the LED device approaches the end of its operating life, the device does not become predisposed to random catastrophic failure due to increased wear, fatigue, or filament evaporation as do incandescent lamps or electromechanical components.

4.1.6 Applications

Single indicator lamps provide one of the most universal applications of the LED device. The indicator normally presents the operator dichotomous or binary type information regarding system or event status. Many lamps accommodate the entire LED color range; red, green, and amber. A variety of mounting and packaging techniques are available, depending on the particular application. The lamps can be panel mounted in standard metal headers with snap-in clips or contained in a standard cartridge holder. Figure 4.2 shows typical packaging dimensions of a Dialight cartridge and LED lamp. The cartridge lamps can also be used to replace existing cartridges that use incandescent lamps.

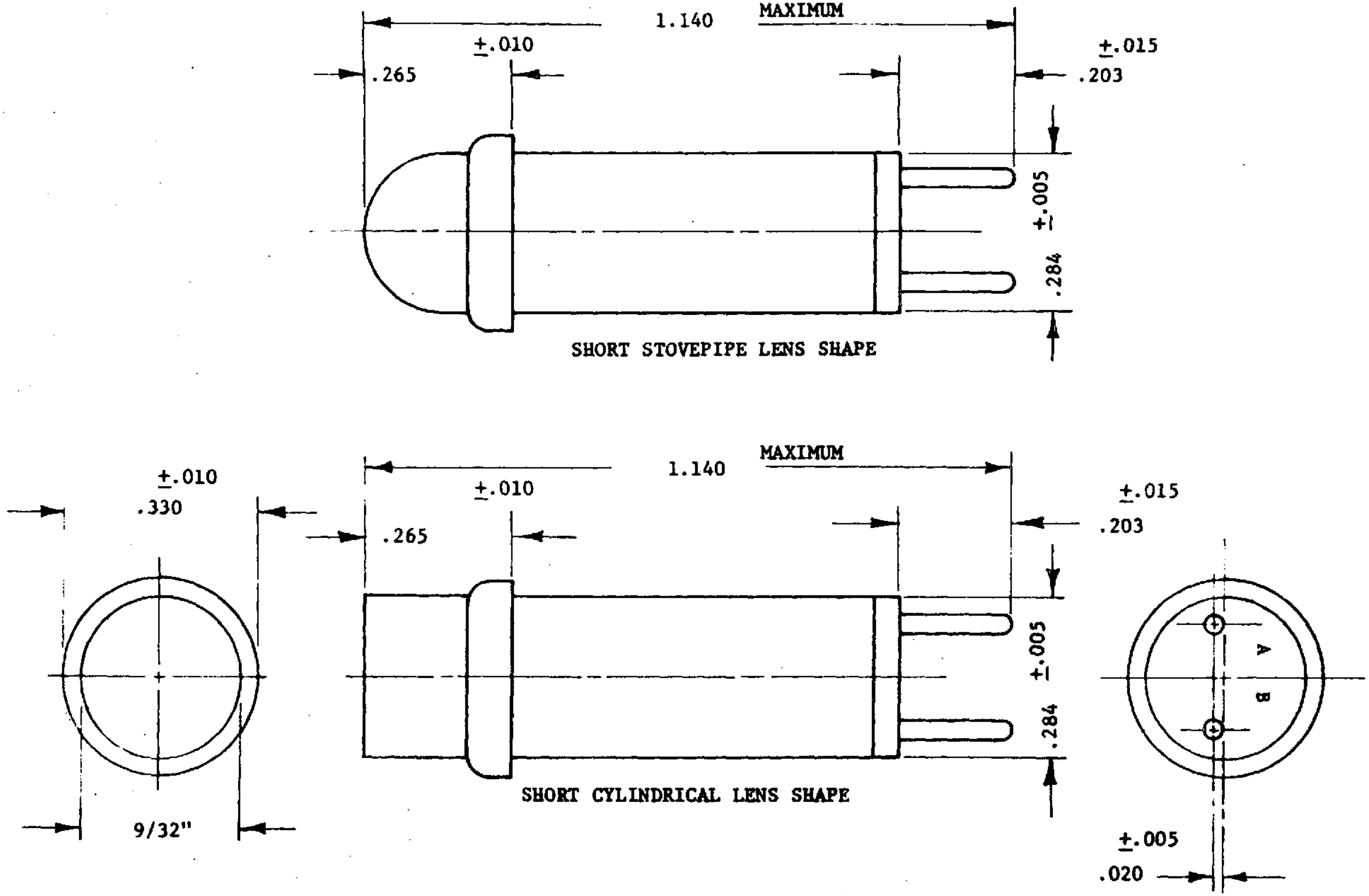


Figure 4.2 Typical LED Lamp and Cartridge Holder

Potential areas for diode application are:

a) Message Annunciators:

Figure 4.3 shows an off-the-shelf unit that back illuminates messages with LED bulbs. Optical isolation is also possible which permits display of multiple messages. The unit shown is manufactured by the Dialight Corporation. Application of this type of device can be adapted to any presentation that requires a fixed format message indicator. The only limitation may be a color requirement that is not compatible with LED emitters.

b) GO/NO GO Status Indicators

With the availability of both red and green LEDs, equipment operation and malfunction states can easily be displayed on the status panel. If panel space is restricted, status information can be transmitted from a remote source through use of noncoherent fiber optics.

4.1.7 Manufacturers

Major semiconductor firms producing LEDs include: Fairchild, Monsanto, Texas Instruments, General Electric, and Motorola. Display manufacturers include: Hewlett-Packard, Opcoa, Litronix, and Dialight.

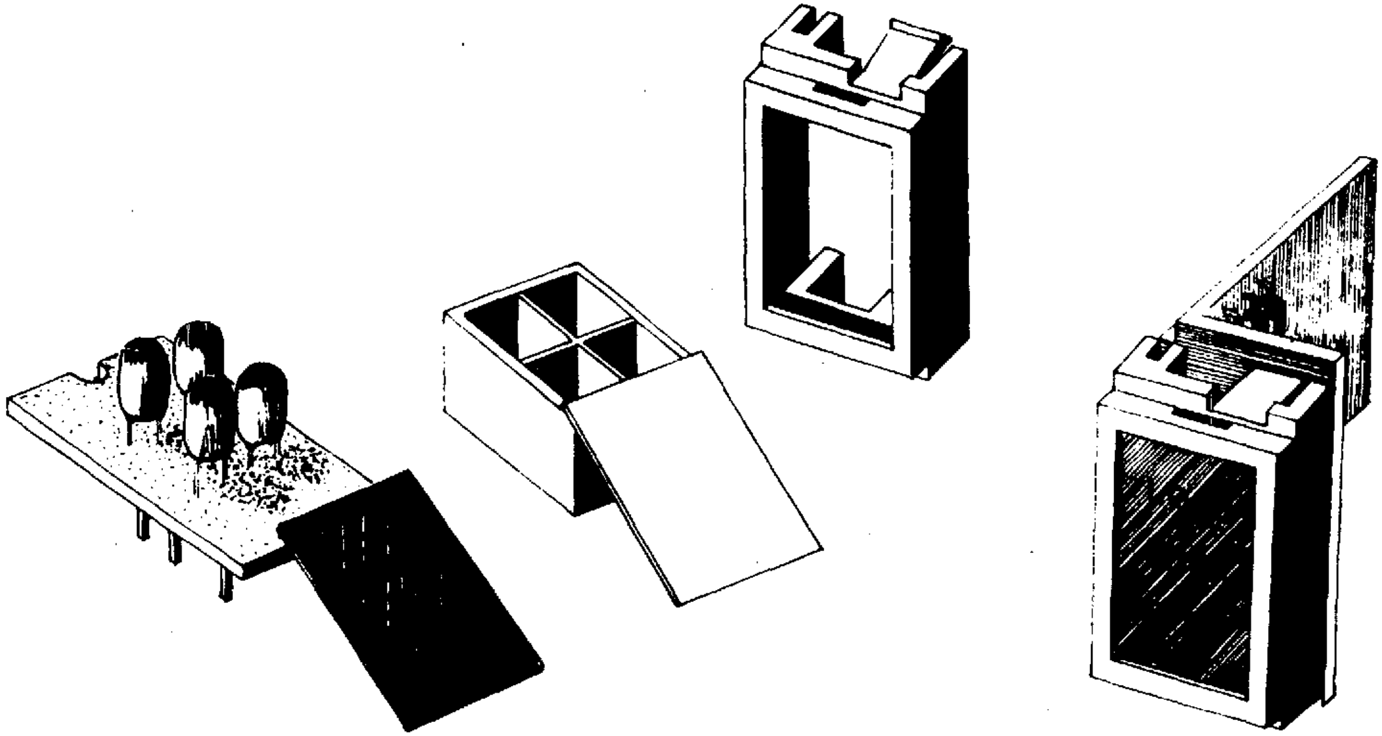


Figure 4.3 Typical Back Illuminated LED Displays

4.2 Liquid Crystals

4.2.1 General Principles

A liquid crystal device is operationally passive. Unlike LED, electroluminescent, or plasma devices, the liquid crystal (LC) display does not emit light; instead it scatters available light. Such a device has distinct advantages in the spacecraft environment. First, since the device reflects light, it can be viewed under the direct incident illumination without concern for information washout. Second, since the device does not emit light, extremely low power is required.

Three types of liquid crystals are available: nematic, cholesteric, and smectic. The nematic LC (most popular for display design) consists of elongated organic molecules arranged in parallel, an ordering highly sensitive to externally applied electronic fields. In the abscence of a field, the molecules assume an orderly pattern, depending on the mixture of the LC material, and the display becomes optically transparent. As a field is applied the nematic material becomes turbulent and the original transparency turns diffuse white, becoming a diffuse reflector of light.

This effect is referred to as dynamic scattering. Dynamic scattering can be terminated and the transparency of the liquid can be restored by turning off the applied voltage. Once the field is absent, there are no more disruptive ions in motion and the molecules return to their pre-established order. The most common liquids used for dynamic scattering are methoxybenzylidene - P'-n- butylaniline (MBBA), and ethozybenzylidene - P'-n butylaniline (EBBA). The resultant mixture of EBBA and MBBA will be nematic from -26° to +40°C. The lower transition temperature is not reversible, that is, the nematic liquid exhibits solidification below -26°C. Thus, the operational properties of the LC display degrade significantly at temperatures below -26°C. As shown in Figure 4.4, the LC display uses a thin-film geometry. Normally a 5- to 25-micron liquid layer is sandwiched between parallel glass sheets that are coated with a transparent conductive material such as tin-oxide or indium-oxide. The top plate has electrodes etched into a 7-segment numeric pattern that faces a rectangular pattern on the bottom plate. In the liquid, the field is confined in those areas where

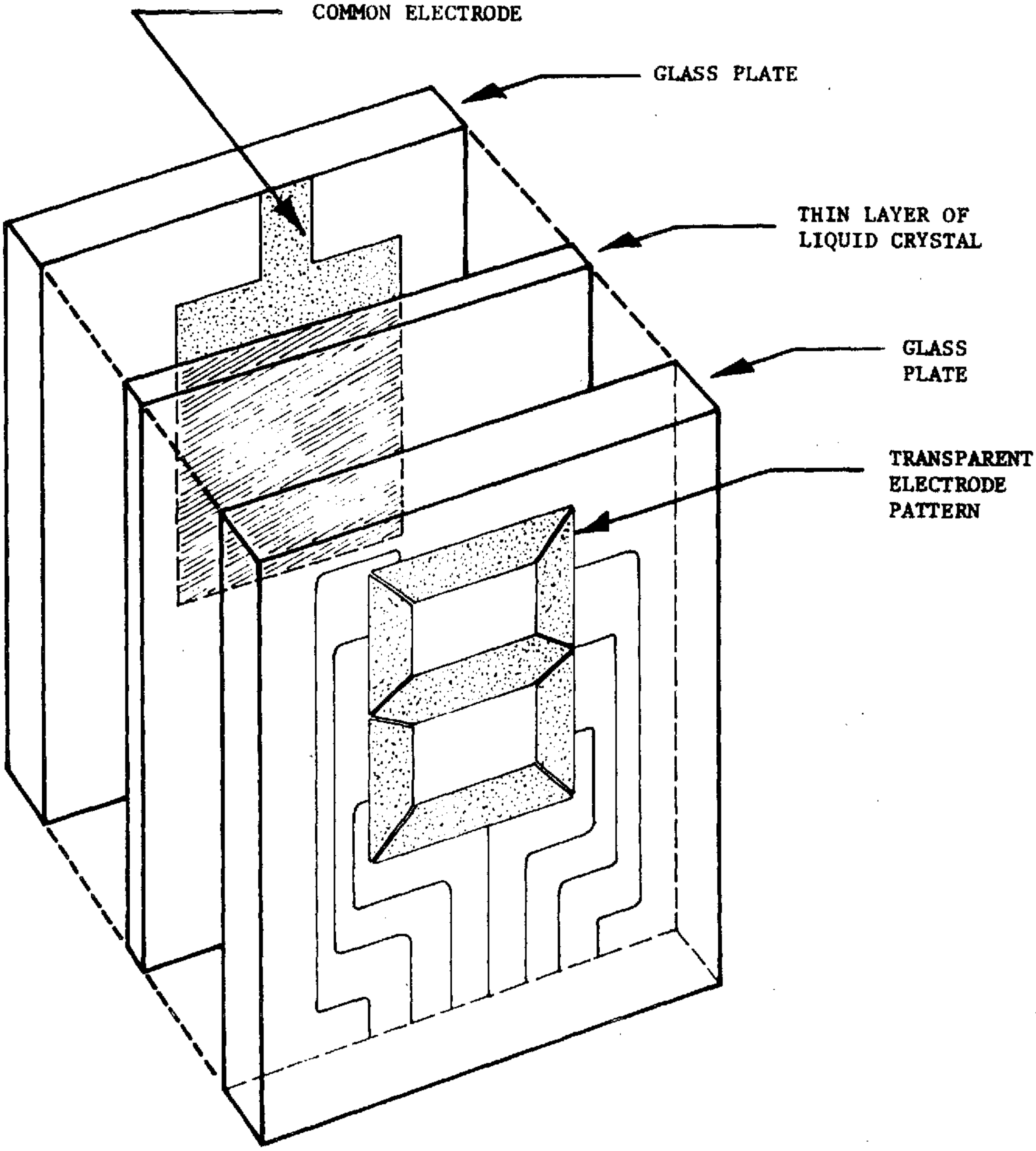


Figure 4.4 Liquid Crystal Display Construction

the patterns overlap. By exciting various electrode parts, a localized change is produced in the molecular order. Because the molecules are highly anisotropic, the reordering causes large-scale changes in the optical properties of the LC. Figure 4.5 shows a cross section of a reflective dynamic scattering device. For this device a black background is added which provides a specular reflection. The display is black in the absence of a voltage and changes to white when excited. The voltage-excited areas become turbulent and are sources of wide-angle light scattering.

Field-effect LC devices are rapidly becoming state of the art and offer a promising new technology in liquid crystals. Without going into in-depth explanation of the field-effect device, the major deviations from the dynamic-scattering display are the electro-optical effects achieved from the twisted arrangement of the molecules and the incorporation of cross polarization. Figure 4.6 shows a cross section of a reflective field-effect device.

4.2.2 Performance Specifications

The salient performance specifications for dynamic scattering LC displays are presented in Table 4.2. The exact specifications depend upon the specific material, thickness, and voltage.

4.2.3 Salient Design Problems

Major design problems defined as inherent to the state of the art LC technology are listed:

a) Reliability

With the dynamic scattering device, life on DC drive is limited due to electrolytic decomposition of the liquid crystal. Although researchers have logged months of DC operation, the opinion is that 10,000 hours of consistent DC operation is unlikely. However, for the AC drive displays the reliability data is quite favorable and 10,000 hours of

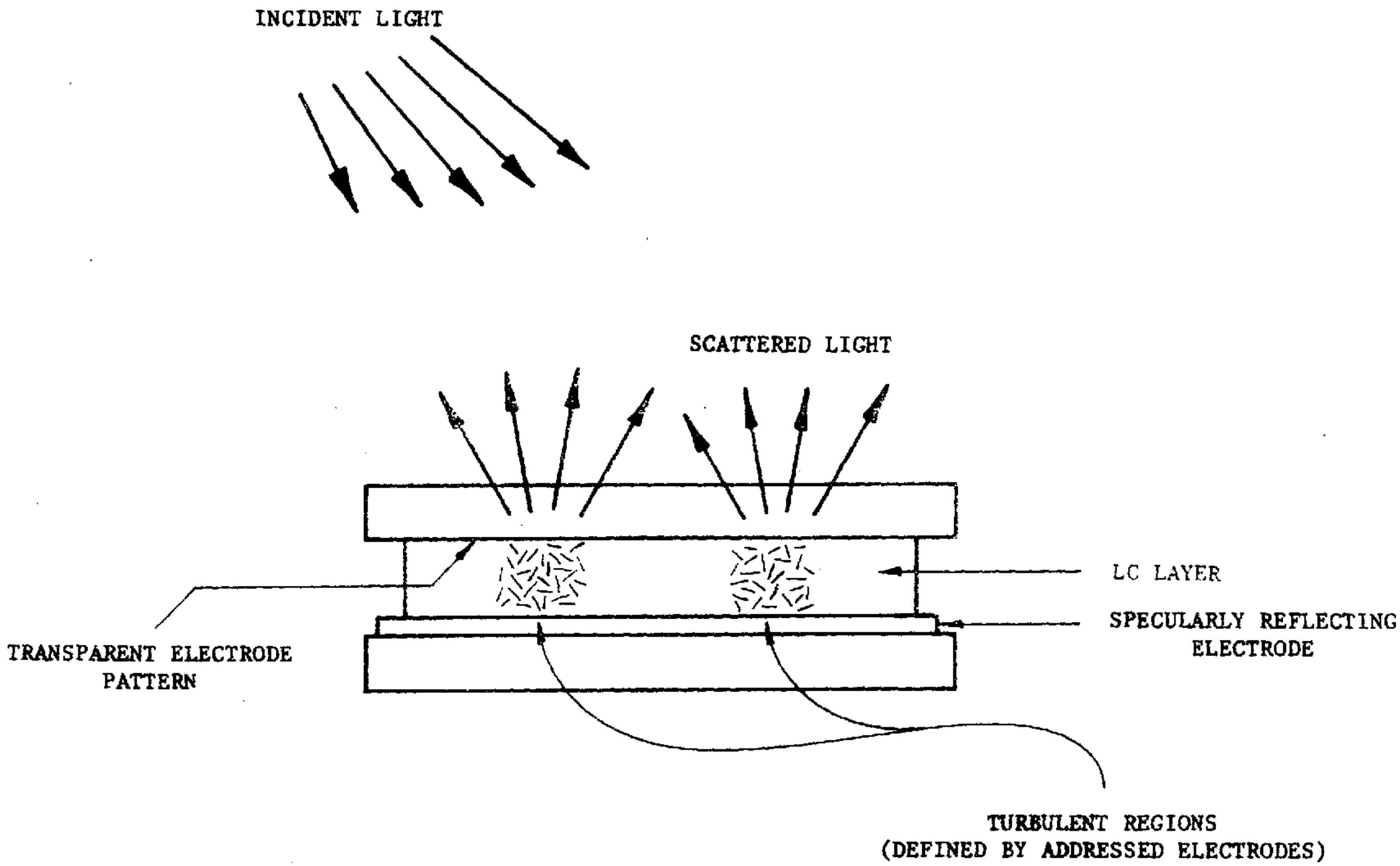


Figure 4.5 Liquid Crystal Reflective Dynamic Scattering Device

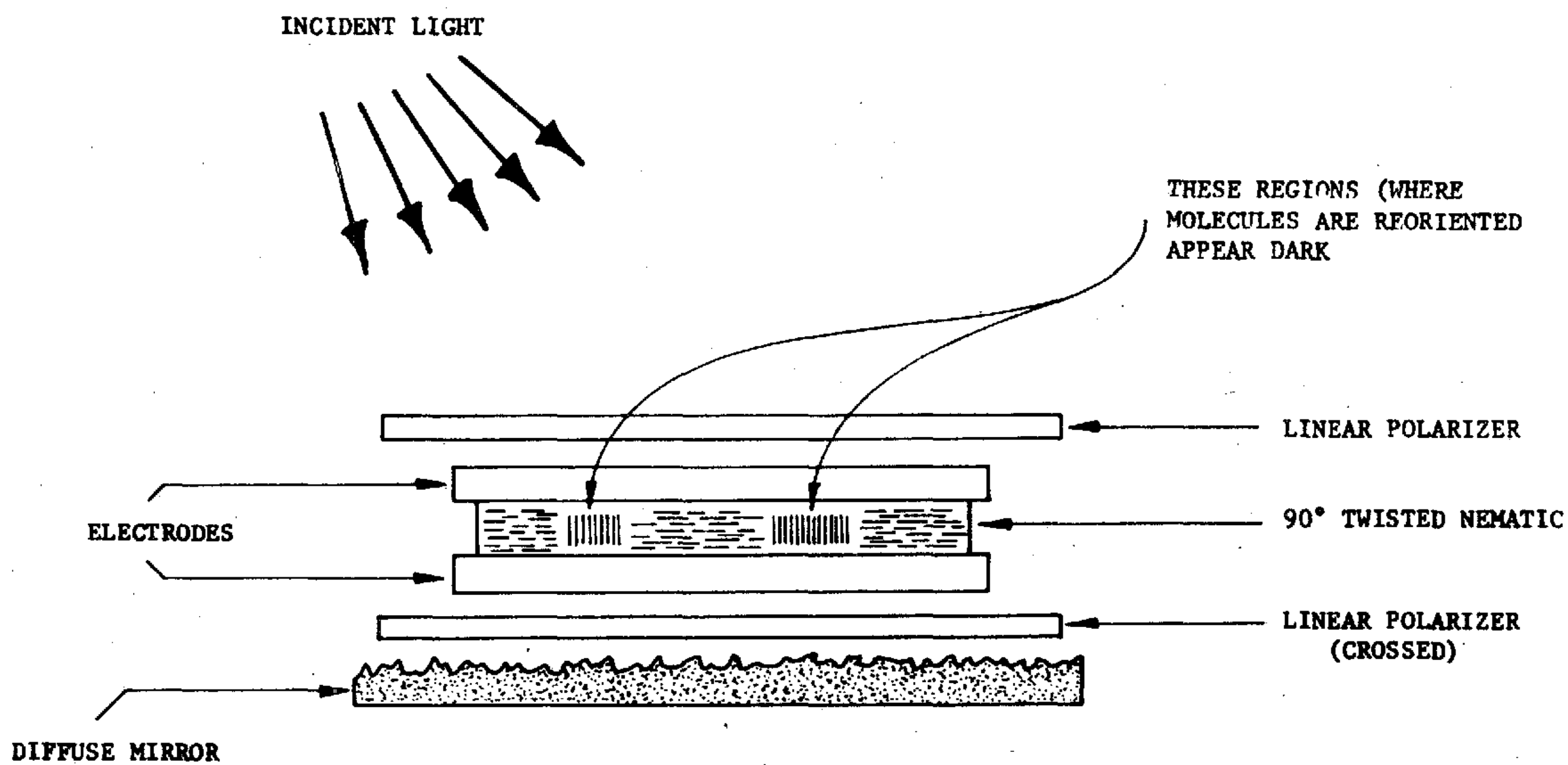


Figure 4.6 Liquid Crystal Field Effect Device

TABLE 4.2

LIQUID CRYSTAL DEVICE PERFORMANCE CHARACTERISTICS

Supply Voltage	12 to 30 Volts
Drive Frequency	DC to 300 Hertz
Current	18 microampere per square centimeter
Capacitance (per digit)	1 picofarad
Operating Temperature*	0° to 47° C
Storage Temperature	-26° to 85° C
Brightness	Reflective
Turn-On Time	5 to 20 milliseconds
Turn-Off Time	50 to 200 milliseconds
Contrast Ratio	20:1
Life	DC: <10,000 hours AC: <10,000 to 100,000 hours
Vibration	Profiles still being determined by manufacturer
Color	Primary colors available if filters are used.
Packaging	Display device is hermetically sealed. Card-edge connectors are most common.

*Considerable development effort is underway to expand the temperature range of these devices. Materials are just becoming available to extend the operating temperature range from -20°C to 100°C.

life has been recorded. AC drive promises 50,000 hour life, especially if more stable LC materials are used.

b) Multiplexing

Multiplexing (time sharing approach to operate all digits with one decoder driver) is limited to four to six digits. General Electric has developed a two-frequency drive technique which allows multiplexing up to 16 digits at a flicker-free refresh-rate. However, the technique requires a higher supply voltage (55V) than does direct drive.

c) Viewability

The viewability of reflective type dynamic scattering displays is less than optimum, due to the interference of the specularly reflected light from the rear electrode. Field effect devices do not have this problem however, the use of polarizers reduces the brightness and viewing angle of the display. Some comparative studies indicate that under various illumination conditions, viewability for the field-effect display is in many respects superior to the dynamic scattering device.

d) Availability

Off-the-shelf units are limited to a 4-digit indicators. Custom work can be done, but long lead times and hesitancy of manufacturers to quote development prices has been encountered. The digital wrist watch and the minicalculator mass markets, attracted by their low power consumption, are just beginning to utilize these devices.

4.2.4 Design Advantages

Liquid crystal technology offers the lowest power using devices of any display system currently available. The LC device and associated driving electronics are well within the maximum voltage and current levels prescribed for intrinsically safe equipments. This is evidenced by the fact that a dynamic scattering device utilizes a current level of 18uA/cm^2 of display area at an excitation voltage of approximately 15 V, but a field-effect device operating at similar current levels requires only 5V for excitation. A representative comparison of presently available off-the-shelf digital meters exhibits the variance in power requirements.

a) 3.5-digit, 7-segment incandescent: 5VDC, 1,000 mA, 5 W (Analog Devices)

b) 3.5-digit, 7-segment LED: 5VDC, 700 mA, 4 W (Digilin)

c) 4 -digit, 7-segment Liquid Crystal: 15VDC, 100 uA, 1.5 mw (RCA)

The available display devices are essentially limited to numeric indicators, although custom panels are becoming available at an increasing rate. This potential application for alphanumeric X-Y addressed matrices and pictorial arrays should not be excluded.

Since the device normally does not emit light, an ambient illumination source must be present in order to discriminate display information. To be visible at all times, irrespective of the presence of ambient illumination, the LC display can be back lighted by placing an incandescent bulb at the rear electrode. This type of display is available although at the expense of an added 2 watts.

The following LC applications are feasible and practicable with respect to the advantages inherent in low power display devices:

a) <u>Portable Units</u>

Battery operated, hand held equipment, are candidates for LC numeric displays. Liquid crystals are even more suitable than LEDs since the LED 7-segment character typically draws around 100 mW per segment whereas LCs draw microwatts.

b) Pictorial Indicators

Custom LC panels are available on an R&D basis.

4.2.5 Manufacturers

Companies currently involved in liquid crystal research include: General Electric, North American Rockwell, Sperry-Rand, Texas Instruments, American Mirro-Systems (AMI), and RCA. Manufacturers with dynamic scattering devices available are: AMI, Optel, Digilin, and RCA. A field-effect displays are marketed by Ilixco and International Liquid Xtal Corp. Ashley Butler Inc., is presently contracting for custom panels with emphasis on the advertising market.

4.3 Plasma (Gas Discharge)

4.3.1 Description

The plasma device derives its luminosity from an electrical discharge in a gas. Although both AC and DC plasma displays have been developed, the DC device is more universally available. In the DC display the breakdown voltage is applied between two electrodes in contact with the gas, allowing a direct transfer of charge between the electrodes and the gas. Light is generated by gas atoms that have been excited through ineleastic collisions with electrons in the discharge.

Several types of plasma indicators are presently available. These include Nixie tubes, single and multicharacter alphanumerics, multirow self-scanning alphanumerics, and a 512X512 line X-Y addressed memory/display panel.

4.3.2 Performance Specifications

Table 4.3 shows general performance data for the Sperry-Rand 3-digit, 7-segment indicator. These data are considered typical for alphanumeric type plasma indicators. Table 4.4 shows specific data for the 512x512 memory panel developed by Owens-Illinois. Burroughs offers several versions of their "Self-Scan" Panel Displays including 16, 32, 80 and 256 character units. Table 4.5 shows specific data for the 256 character unit.

TABLE 4.3

Seven-Segment Plasma Device Performance Specifications

Supply Voltage	130 to 170 VDC
Voltage Drop	150 VDC
Current (per segment)	125 to 200 µA
Capacitance (per digit)	5 picofarads
Operating Temperature	0° to $+70^\circ$ C
Storage Temperature	-55° to $+155^\circ$ C
Brightness	100 to 600 ft.-l.
Color	Orange-Red
Life	100,000 hours
Shock	50 g, 1/2 sine wave, 11 msec pulse duration, five drops in each of six planes
Vibration	0.2 inch DA, 10 to 20 Hz; 2 g, 14 to 2,000 Hz; 10 minutes in X, Y, and Z planes. 0.1 inch DA, 10 to 44 Hz; 10 g, 44 to 800 Hz; 10 minutes in X, Y, and Z planes
Packaging	Thin construction, all digits permanently aligned. Some devices have pins or leads at one end, others utilize card-edge connector, or rear package pins varying according to the number of digits/package.

TABLE 4.4

512x512 Plasma Display Panel
Performance Specifications

Breakdown Voltage	105 to 125 VAC
Sustaining Voltage	100 to 110 VAC
Drive Frequency	60 Hz
Current (per panel)	1.8 A
Capacitance (per panel)	3,000 picofrads
Operating Temperature	0° to +55° C
Brightness	50 ft.-l.
Contrast Ratio	25:1
Color	Orange-Red
Life	The plasma panel is still undergoing concentrated life and environmental testing at Owens-Illinois. Present data shows ongoing life tests at 13,000 hours.
Vibration	Abbreviated tests performed to MIL-STD-810B. 5 to 500 Hz vibration at 5 g in X, Y, Z planes. Higher g loading tests are forthcoming.
Shock	Impact shock of 150 g in X, Y, Z planes
Humidity	Relative humidity testing performed in accordance with MIL-STD-810B method 518.

Table 4.5

256 Character, Self-Scan Panel Display
Performance Specifications

Character Capacity	256
Character Format	5x7 Dot Matrix
Text Format	32 Characters/row 8 rows
Dot Spacing	.040"
Character Size	0.2" wide x .28" high
Brightness	50 ft. L nominal
Contrast Ratio	20:1
Color	Neon-orange
Panel Scan Rate	85 Hz
Operating Temperature	0 to 50°C
Storage Temperature	0 to 70°C
Humidity	0 to 85°C

4.3.3 Design Advantages

Plasma devices do have some attractive features. The numeric devices require less current than any other light emitting device currently available. This includes LEDs which nominally require around 35 mA per segment as compared with 125 uA for the plasma indicator. Figure 4.7 shows the basic construction of a plasma numeric indicator. It is the opinion of the device manufacturer that in the case of package failure it would be highly unlikely that an anode to cathode short would occur since the anode is a plated conductive film deposited on the inside surface.

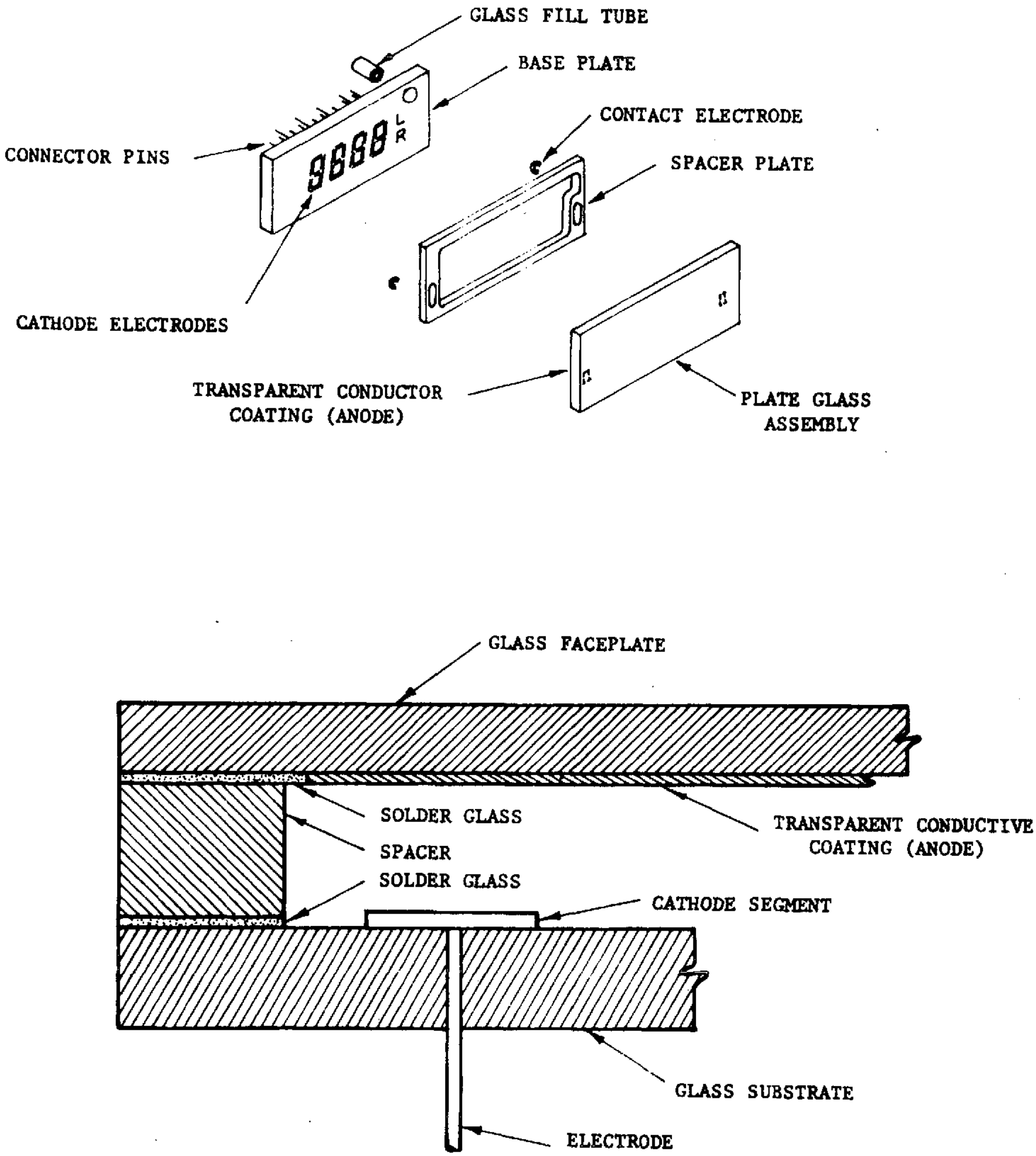
The plasma numeric display is also easier to read than the LED numeric display. Its color is more aesthetically pleasing to the viewer than the red LED and being in the orange region of the spectrum the emitted light is closer to the eye's maximum sensitivity range.

A major advantage of the plasma device is its comparative cost. General Motors recently completed a comparative cost study of various off-the-shelf displays. Figure 4.8 summarizes the results of the study. The comparison included the cost of: (1) the display, (2) associated electronic components, (3) circuit card fabrication, assembly, and test, (4) interconnection and packaging, (5) contrast filter, and (6) power supply. As shown, the plasma display has the lowest price of the sampled devices.

4.3.4 Random Access Plasma Display Panel

The 512x512 line plasma display panel has potential application for display of information when operating a vehicle from a remote station. In remote tracking the operator must have both control and real time visual feedback of the vehicle dynamics. In order to close this operational loop, information must be presented that locates the vehicle within a coordinate system, provides sufficient rate information and allows dynamic feedback when a command is given. This type of device is normally referred to as a situation display.

An off-the-shelf unit that incorporates the flexibility of the CRT without the associated adverse characteristics is the Owens-Illinois Digivue plasma panel.



Plasma Device Mechanical Construction

Fig. 4.7

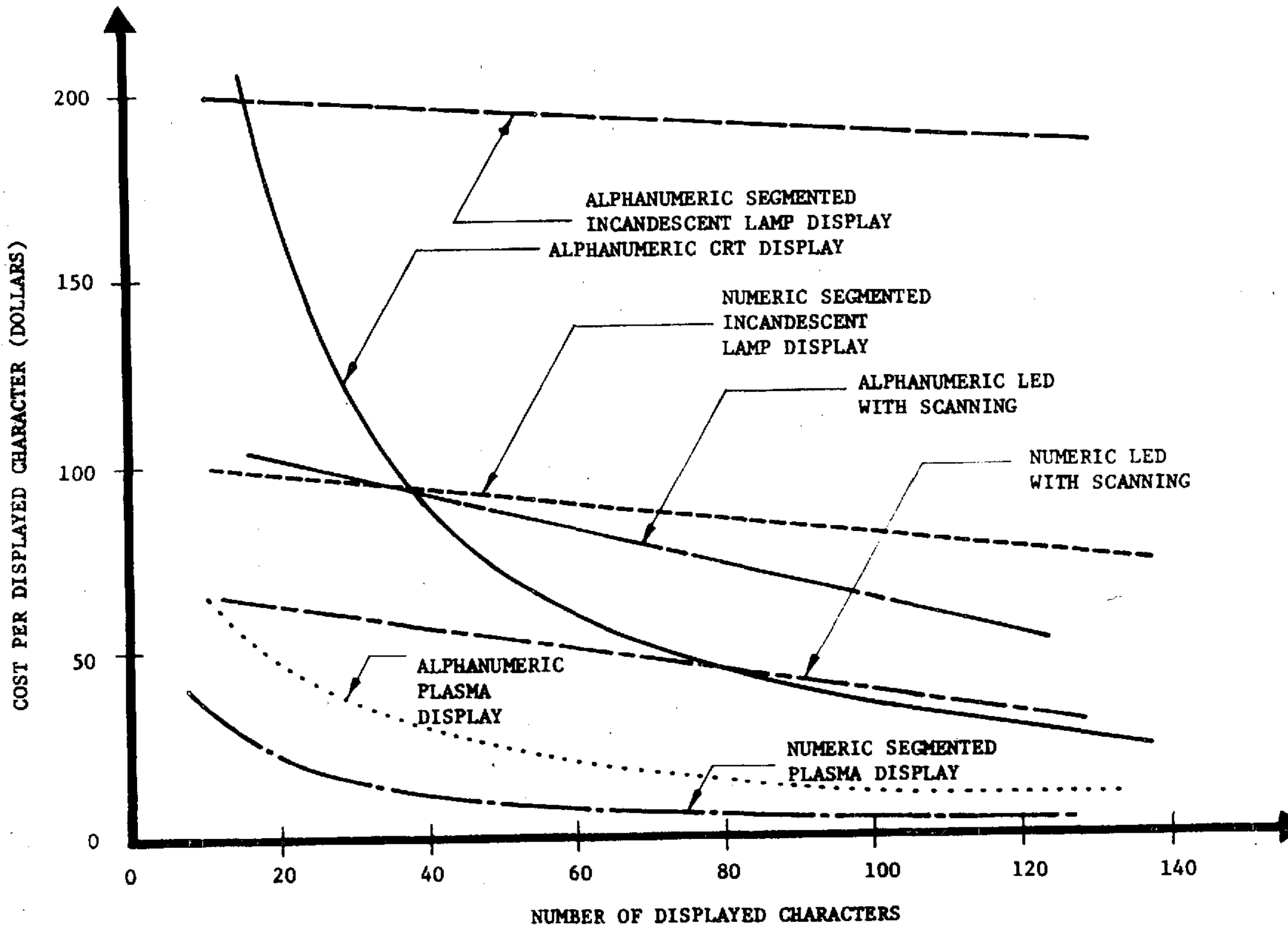


Figure 4.8 Cost Comparison of Display Devices

Figure 4.9 shows the basic construction of the Digivue panel. In essence, the display is a typical gas discharge device with memory capability. Two glass plates are separated by a gas mixture. Row and column electrodes are placed orthogonally to the substrate glass and deposited with a thin dielectric. A sustaining AC voltage (approximately 100 V) is maintained across the panel. The sustaining voltage is insufficient to ignite the gas discharge, but if a selected cell defined by the intersection of an electrode pair is addressed with a higher voltage (approximately 120 V) which exceeds the breakdown potential of the gas, a discharge is initiated. The cell then sustains itself at a preceived continuous rate until the cell is addressed in such a way that the stored charge is allowed to return to zero. Thus, a cell can be turned on or off in a random access manner. This inherent memory feature eliminates the requirement for a refresh buffer memory.

The display panel has other inherent characteristics which in many respects either parallel or exceed the capabilities normally ascribed to the CRT terminal. It is also rugged in construction, reliable, and requires low power.

Zenith Radio Corporation recently demonstrated an experimental 80 column by 212 raw gas discharge panel displaying a TV picture. However, many problems remain to be solved before such a device would be practical.

In conclusion, the plasma panel provides both a desirable and feasible alternative for a flexible format display terminal.

4.3.5 Manufacturers

Major manufacturers of alphanumeric plasma indicators include: Amperex, National Electronics, Burroughs, Soney and Sperry. Owens-Illinois produces the graphics plasma panel.

4.4 Electroluminescent

4.4.1 Description

In its most elementary form, the electroluminescent (EL) lamp is a thin layer of light-emitting phosphor material sandwiched between two electrically conductive surfaces, or electrodes. When an alternating voltage is applied to the two electrodes, the generated alternating electric field engergy

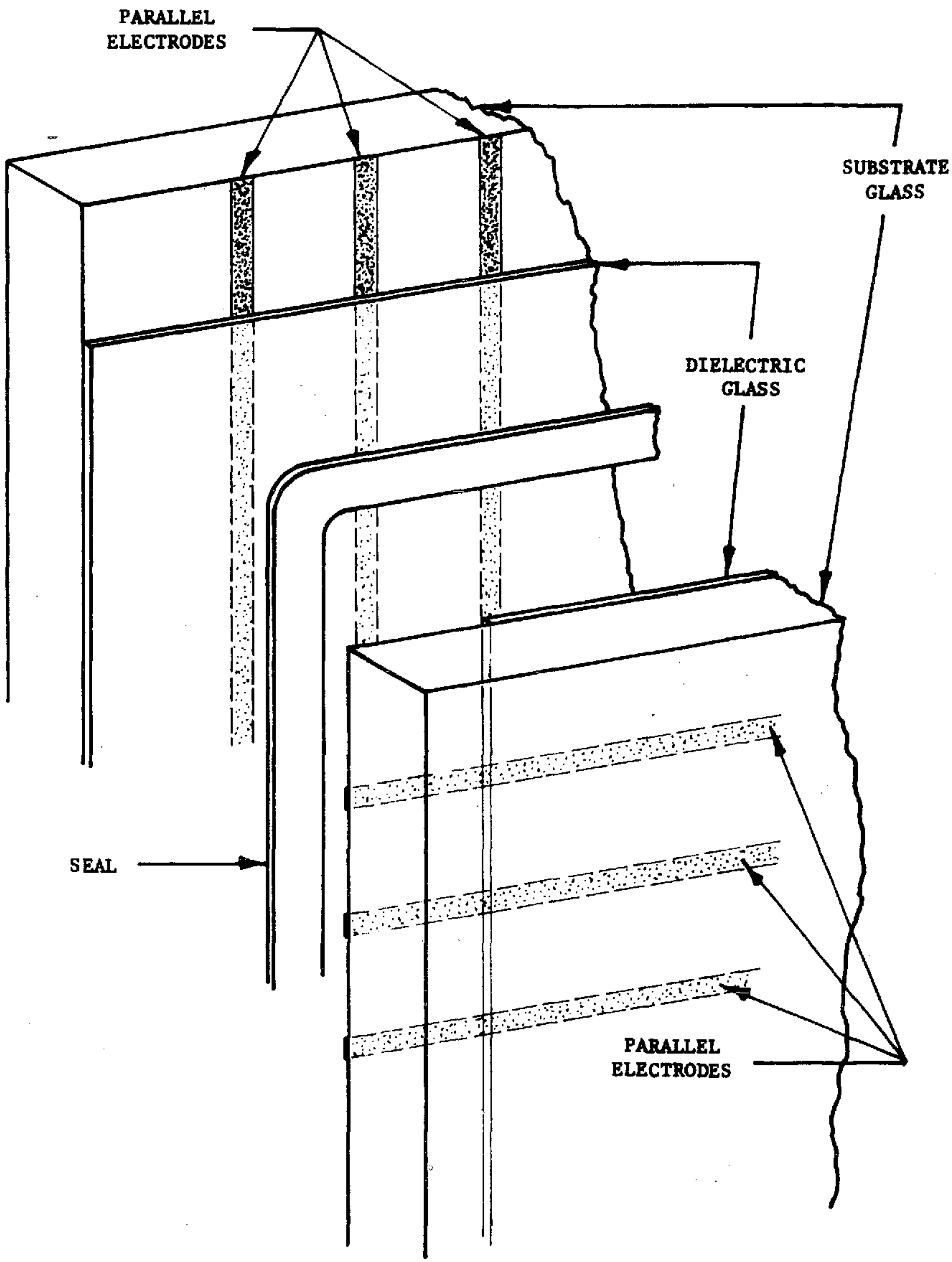


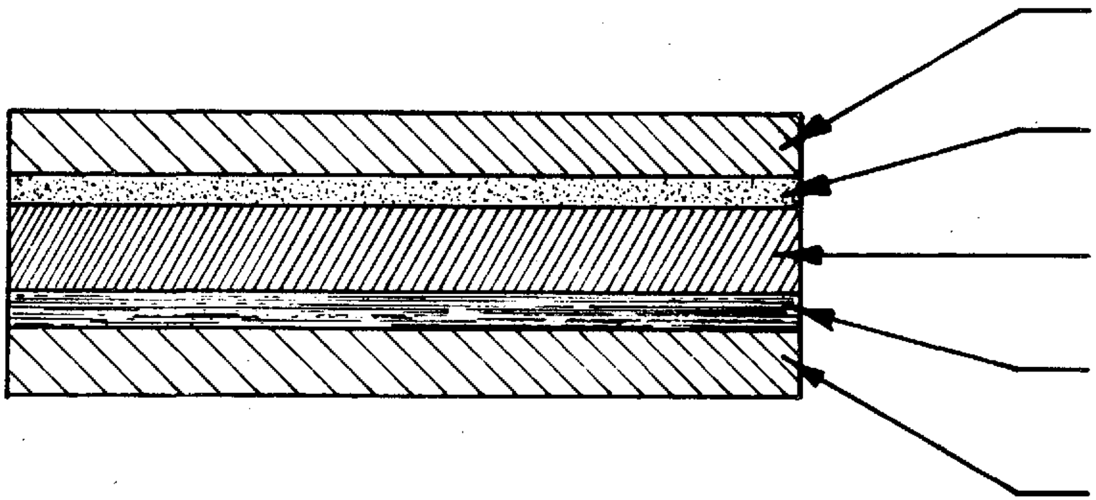
Figure 4.9 Basic Digivue Display/Memory Panel Construction Diagram

is converted to light radiation thereby causing the phosphor material to emit light. This phenomenon is commonly referred to as electroluminescence. To make the lamp useful, one electrode must be made light-transmissive. Normally this is accomplished by applying a clear conductive coating to one side of a sheet of glass. The phosphor is then deposited on the clear conductive coating, and the second electrode is deposited on the back of the phosphor layer. This electrode is usually some metallic material such as aluminum or indium which is evaporated onto the phosphor layer. Figure 4.10 shows a cross section of a typical EL lamp.

Although several types of EL materials have been used, the most useful present day EL phosphors are the sulphide and sulphoselenide types. By varying the materials and manufacturing process, phosphors can be developed which will emit various colors of the spectrum. The four basic colors of EL lamps are white, green, yellow, and blue. Many other colors are attainable with the use of photoluminescent overlays. Although color is primarily dependent on phosphor composition, it is also a function of the frequency of the excitation voltage. The brightest and most efficient EL phosphor is green at low frequencies and shifts to blue as frequency is increased.

DC electroluminescent devices are also available but in very limited quantities. Phosphor Products Company, Limited of London, England, is building practical, competitive DC EL displays. The active electroluminescent material is zinc sulphide rather than a conventional phosphor, and it is deposited as powder rather than as a thin film. The devices are fabricated as sandwich cells, employing transparent conducting glass and evaporated aluminum as the anode and cathode respectively, and are encapsulated in a thin pack construction. The most prevalent color is yellow although green and blue units have been built.

The newest EL device is the light emitting film (LEF) device. This device uses principles similar to those of the conventional EL device but different technology and materials. The device was introduced and developed by Sigmatron. The display is fabricated by depositing a thin film of phosphor on a substrate previously coated with a transparent electrode. The phosphor, a transparent polycrystalline film, provides the active portion of the display device. The device is then coated with a light absorbing dielectric layer that provides a dark background against which the light emitted by the excited phosphor can be viewed. Figure 4.11 shows an expanded sectional view of the Sigmatron LEF device.



Cross Section of Typical EL Lamp Construction
Figure 4.10

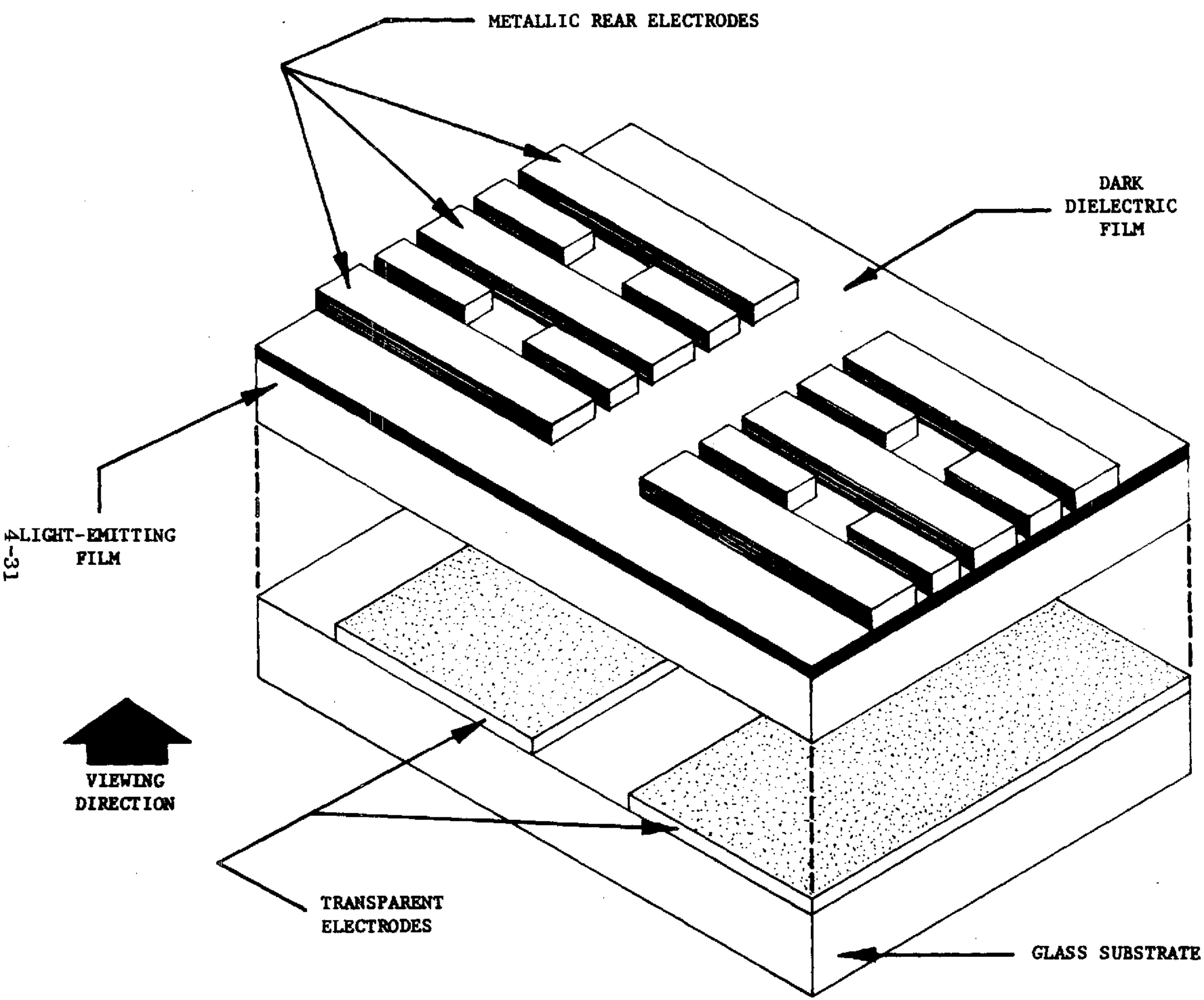


Figure 4.11 Sigmatron's LEF Device

4.4.2 Performance Specifications

Table 4.6 shows typical performance data for the three electroluminescent devices.

4.4.3 Salient Design Problems

The major problem historically associated with EL devices is low brightness and marginal contrast ratios. The typical alphanumeric indicators have luminance values between 7 and 15 ft.-l. with low contrast values. Since electroluminescence is the direct conversion of electrical energy to light radiation, the amount of light output increases with the applied voltage. Also due to the capacitive nature of the lamps, an increase in frequency of alternating voltage increases light output. Therefore, as more display luminance is required a penalty is paid in voltage and frequency levels. The extent of this penalty is of course a direct function of the display application and ambient illumination. In most commercial applications ambient conditions have generally precluded the widespread usage of EL devices and some major manufacturers, e.g., Sylvania have either terminated or severely cut back their EL devices product line.

Another significant consideration is EL lamp life. AC EL lamps have the shortest lift characteristics of any of the sampled solid state devices. Again, the life of the device is a function of initial brightness requirements. Most EL life tests are conducted based on half-life, e.g., the period of time during which the lamp's brightness decays to 50 percent of its initial brightness. However, half-life does not signal the end of an EL device's "useful life", and the latter will probably be several thousands of hours, depending on the ambient viewing conditions. The driving application variables are therefore ambient illumination and viewing requirements.

The DC EL display, especially the LEF device, offers highly visible, good contrast characters and increased reliability. The salient disadvantage of the LEF device is the requirementfor high frequency drive voltages (20 kHz to 30 kHz) and much higher peak-to-peak voltages (600 V).

TABLE 4.6

Typical Electroluminescent Lamp Performance Specifications

DEVICE SPECIFICATION	AC EL	DC EL	LEF	COMMENTS
Supply Voltage	115 to 250 V	80 to 100 V	Low Voltage DC Supply	For LEF Device 600 V P-P Drive voltage required to excite phosphor. Preferred excitation occurs at a frequency of 20 to 30 kHz
Drive Frequency	60 to 400 Hz	DC	DC	
Power	20-50 mW/digit	500 mW/cm^2 Panel Area	<50 mW/digit	
Operating Temperature	-70° to +100° C	Data not available	-70° to +70° C	
Brightness	1 to 20 ft.-l. (normal)	100 ft.-l. (max)	>15 ft.-l.	
Life	Up to 5,000 hours half life from initial brightness of 20 ft.-l. operation at 400 Hz	5,000 hours at 10 ft.-l. 1,000 hours at 100 ft.-l.	28,000 to 96,000 hours	Sigmatron conducted a number of tests with devices operated primarily on a time averaged brightness level of 10 ft.-l. Results to date indicate a MTBF of over 23,000 hours.
Vibration		Data not available	Data not available	

TABLE 4.6

Typical Electroluminescent Lamp Performance Specifications (Concluded)

DEVICE SPECIFICATION	AC EL	DC EL	LEF	COMMENTS
Color	White, green, yellow, and blue	Yellow primarily; green and blue units developed but only at low brightness and low efficiency levels.	Yellow	

4.5 Solid State Device Trade Evaluation

4.5.1 Trade Criteria

Table 4.7 presents a comparative evaluation of salient device criteria. The criteria were selected based on technical and operational significance for devices specifically selected for use in the spacecraft environment.

Ascending rank numbers 1 through 3 were assigned and identified in the upper left corner of each matrix cell. Because the ranking relates to application under a specific set of conditions, it is possible, for example, to have multiple "firsts" (1's) for a characteristic across the various device columns. Therefore in addition to an interdevice comparison, the assessment criteria were also ranked with respect to their particular desirability in the spacecraft. No attempt was made to weigh the criteria factors because of the high subjectivity inherent in such a comparison technique.

4.5.2 Trade Results

The LED and plasma devices have certain generic advantages when compared with the defined list of characteristics. This is evidenced by the high percentage of No. 1 ratings tabulated for each device. The liquid crystal and electroluminescent devices are tightly grouped in second position with approximately equal No. 1 ratings. The largest number of least desirable, or No. 3 ratings, are ascribed to the liquid crystal and electroluminscent devices with plasma showing a close second. It is noteworthy that the LED device is not rated least desirable for any of the intercompared characteristics. The LED and liquid crystal devices are the only solid state devices that require low operational power and can be assumed to be intrinsically safe without extensive empirical testing.

The liquid crystal device offers some distinct and unique advantages. First, and of fundamental importance, is the fact that the liquid crystal device requires the least power of any comparable display device on the commercial market. This, of course, assumes that the device is the reflective, not the back-illuminated, type. Backlighting requires an additional 2 watts for the conventional 3.5-digit display. The reflective device far exceeds electrical safety criteria. The LC and LED are both given No. 1 ranking for electrical safety even though the reflective LC requires significantly less power.

The areas where significant variation does not exist between the LC and the LED include visibility and availability. The LC device exhibits some limiting visibility characteristics in forms of excessive glare or narrow fields of view. These problems are respectively inherent to the dynamic scattering and field effect displays. Although efforts are being made to alleviate the visibility problems, current researchers consider the factors significant and possibly detrimental in many display applications. The major independent variable for the LC device is, of course, the requirement for relatively high ambient light.

The LC device was also ranked low with regard to availability, although this situation appears to be rapidly changing.

In summary, LC technology is still emerging from the development stage, and although significant research is being conducted by a fairly large number of concerns, only a very limited product line is commercially available.

TABLE 4.7 COMPARISON SUMMARY OF SOLID STATE DEVICES

CHARACTERISTIC	LIGHT EMITTING DIODE	LIQUID CRYSTAL	PLASMA (GAS DISCHARGE)	ELECTROLUMINESCENT EL PHOSPHOR	ELECTROLUMINESCENT LIGHT EMITTING FILM
Power Requirements	1 2 to 5 VDC, 60 to 500 mW, depending on display size and other factors. Device is considered to be low power and intrinsically safe according to available safety criteria	1 Dynamic scattering devices require 12 to 60 V p-p with drive varying from dc to 20 to 100 Hz at low currents ($18 ua/cm^2$). Field effect devices require 5 to 8 VDC at very low current (approx.)10% of dynamic scattering current). LC devices require the lowest power of any available display. Intrinsic safety is assured.	3 130 to 170 V, 150 to 200 mW per digit. Relatively high supply voltage required compared to LEDs and LCs.	3 115 to 250 V. 50 to 100 mW per digit. 60 to 400 Hz drive frequency considered typical for EL display. However voltage and frequency are highly dependent on display brightness and color requirements.	3 400-600 V p-p pulse groups with 30 kHz carrier frequency and 1 kHz repetition rate although other combinations can be used. Current is approximately 60 mW per digit.
Availability/Flexibility - Alphanumeric	1 Multiple digit indicators readily available from several manufacturers. Good format flexibility.	3 Limited availability, most manufacturers still in R&D phase. 2-to4-digit indicators can be purchased in small quantities. 8 digit version in production.	1 High availability, displays up to 256 characters available in large quantities. Fair format flexibility.	2 Available by small number of manufacturers. Good flexibility.	3 Single manufacturers for both LEF and zinc sulphide indicators, limited availability, numerics only.
- Custom Arrays	1 Multiple manufacturers specializing in custom panels and supporting electronics.	2 Custom manufacturers are available but appear to be only in a prototype production effort.	3 No know custom plasma displays available.	1 Custom large area displays available. Custom production appears to be good.	3 Both LEF and zinc sulphide manufacturers claim customizing capability but neither have as yet produced a product.
Visibility - Color Variation	1 Predominately red with wave length peaking around 650 nanometers. Green and amber are also available allowing full check reading and cooling	3 Primarily scattered light on a dark background. Color variation technically feasible either by injecting colored dye into the nematic liquid or by the addition of colored translucent overlays. Techniques not immediate state-of-the-art.	3 Neon red-orange only. A new technique is being researched which provides readout of any color from red through yellow by mixing of the gas and varying the current into a matrix of gas-filled phosphor coated cells.	2 Yellow, blue, white, and green. Color determined by phosphor selection.	3 Yellow only.

TABLE 4.7 COMPARISON SUMMARY OF SOLID STATE DEVICES (continued)

CHARACTERISTIC	LIGHT EMITTING DIODE	LIQUID CRYSTAL	PLASMA (GAS DISCHARGE)	ELECTROLUMINESCENT EL PHOSPHOR	ELECTROLUMINESCENT LIGHT EMITTING FILM
- Contrast	2 High luminance but low contrast between emitter and surrounding areas. Emitters can be pulsed with high current to maximize brightness but technique does degrade useful life. Contrast enhancement filters are required.	1 High contrast only if ambient light is provided. Contrast varies proportionally to incident illumination during all readout occasions.	1 High contrast in all ambient light conditions.	3 Characteristically low luminance and marginal contrast in ambients above 50 ft.-l. Contrast enhancement filters are mandatory in medium ambients.	1 Low luminance but excellent contrast. High illumination ambients appear not to be a problem with LEF. Filters are generally not required.
-Sensitivity	2 Red LED's emit light in a spectral region where a segment of the user population finds difficult to discriminate. This phenomenon is noticed mostly in applications where digits are changing at a rapid rate. Use of red LEDs may provide a recognition problem in some applications. Green and amber LEDs do not generate a sensitivity problem.	1 Dynamic scattering of achromatic light, visual sensitivity not affected.	1 No sensitivity problems identified.	1 Yellow and green EL have good readability under most conditions. Blue presents some problems in a dark environment.	1 No sensitivity problems identified.
-Field of View	1 Planar construction viewing angle 150°.	3 Planar construction. For light scattering devices viewing is degraded because of glare. For field effects devices field of view is reduced to around 40 degrees because of polarizers.	1 Planar construction viewing angle in excess of 160°.	2 Planar construction, viewing angle 130°.	1 Planar construction, viewing angle 170°.
-Maximum Viewing Distance	1 0.25 inch characters readable at approx. 10 ft.	1 If adequate ambient illumination is supplied 0.65 inch characters are readable up to 25 ft.	1 0.33-inch characters readable at 20 ft.	Information not available.	Information not available.

TABLE 4.7 COMPARISON SUMMARY OF SOLID STATE DEVICE (continued)

CHARACTERISTIC	LIGHT EMITTING DIODE	LIQUID CRYSTAL	PLASMA (GAS DISCHARGE)	ELECTROLUMINESCENT EL PHOSPHOR	ELECTROLUMINESCENT LIGHT EMITTING FILM
-Format Variation	1 Fixed (alphanumeric)	3 Fixed (numeric)	1 Fixed (alphanumeric)and flexible (matrix array)	1 Fixed (alphanumeric) and flexible (matrix array)	3 Fixed (numeric)
Reliability -Life	1 Monsanto quotes test data for LED lamps as follows: life 1,000,000 hours, MTBF 500,000 to 700,000 hours, estimated life MTBF 57 to 79 years.	2 Specific test data not available. Manufacturers estimate DC displays less than 10,000 hours, AC displays 10,000 to 100,000 hours.	1 100,000 hours	3 Life a function of initial brightness requirements. TECHWEST ENTERPRISES LTD. claim half-life at 5,000 hours from initial brightness of 20 ft.-l. Other estimates range from 1,000 to 3,000 hours. Device is rated low because of high brightness required to maintain acceptable contrast under illumination.	2 28000 to 92000 hours SIGMATRON claims empirical test data.
-Vibration	1 Monsanto lamp. Fatigue - MIL-STD 883 method 2005, 20g, 60 Hz X,Y,Z 32 hours each plane non-operating. Variable Frequency-MIL-STD 883 method 2007, 20 g. 60 Hz 100-2000-100 Hz 4 cycles X,Y,Z planes. Acceleration - MIL-STD 883 method 2001, 20,000 g. Y plane only, 1 minute.	2 Detailed test data not released by manufacturers. RCA claims that tests on 3"x5" cells passed MIL-STD-202D criteria for shock, vibration variable frequency and fixed frequency, vibration fatigue. Manufacturers [illegible] strongly advocate high vibration and shock tolerances.	1 SPERRY RAND quotes the following specifications for plasma devices: 0.2" DA, 10 to 14 Hz; 2 g 14 to 2,000 Hz. 0.1" DA, 10 to 44 Hz; 10 g, 44 to 800 Hz. All tests in X,Y, and Z planes.	1 10 g minimum 10 to 2,000 Hz.	Specific test data not released by manufacturer.
-Shock	1 Monsanto MIL-STD 883 method 2002, 1500 g, X, Y,Z planes. Devices are all considered rugged in construction.		1 50 g, 1/2 sine wave, 11 m sec pulse duration 5 drops in each of six planes.	1 15 g in X,Y, and Z planes.	Specified test data not released by manufacturer.

TABLE 4.7 COMPARISON SUMMARY OF SOLID STATE DEVICES (continued)

CHARACTERISTIC	LIGHT EMITTING DIODE	LIQUID CRYSTAL	PLASMA (GAS DISCHARGE)	ELECTROLUMINESCENT EL PHOSPHOR	ELECTROLUMINESCENT LIGHT EMITTING FILM
-Dust	Testing not performed by device manufacturers.	Testing not performed by device manufacturers.	Testing not performed by device manufacturers.	1 Completed testing in accordance with method 510.1 of MIL-STD-810A.	Testing not performed by device manufacturer.
-Humidity	1 Monsanto Lamp, MIL-STD-883 method 1004. No initial conditioning 24-hour cycles from 25° to 65°C @ 90% to 98% relative humidity; 10 cycles	Information not available	Information not available.		Information not available.
Economics -Display	2 Costs/digit range from \$1.60 for 8-digit 1/8-in numbers (LITRONIX) to \$7.50 for MONSANTO's "MAN I".	2 Present cost/digit from \$1.60 to \$5.00. OPTEL predicts that future LC prices will be in the \$0.50 range.	1 Cost/digit range from \$1.00 to \$2.00. Lowest cost for off-the-shelf units.	2 \$2.00/digit for 2- to 4-digit readouts.	2 Cost should be proportional to panel area. Costs of \$0.50 to \$2.00/digit are estimated for early 1973. Present costs are around \$1.75/digit. Interface costs are expected to be high.
-Decoder/Driver	Costs/digit range from \$0.40 to \$1.65.	None currently available.	Cost/digit range from \$0.60 to \$1.50.	Information not obtained	Information not obtained
RANK TOTALS	1 - 10 2 - 3 3 - 0	1 - 4 2 - 4 3 - 4	1 - 9 2 - 0 3 - 3	1 - 5 2 - 3 3 - 3	1 - 3 2 - 2 3 - 5

SECTION 5

ELECTROMECHANICAL DEVICES

5.1 Incandescent Readouts

5.1.1 Description

The most popular and widely used digital displays are those employing incandescent filaments for providing a seven segment numerical display. From a cost standpoint, useability in the widest environmental ranges, choice of colors, and compatibility with IC logic levels, no other device has approached the versatility of incandescent filament displays.

Directly viewed filaments, where the observer looks directly at the filament, comes in flat rectangular packages, while some manufacturers use standard long life subminiature bulbs and fiber optics to form a segment composed of dots. The latter device comes in a package about two inches long. With fiber optic transmission, the observer is still looking at the filament, through the high transmission efficiency of the fiber optics. In this case the seven lamps plus the decimal point lamp are enclosed in a heat sink to prevent excessive temperature rises.

5.1.2 Operating Characteristics

The temperature at which an incandescent lamp is designed to operate is a compromise between the luminous output and operating life. At greater luminous outputs, temperature increases cause a greater rate of filament evaporation and, thus, shorten life. Tungsten is used because of its low rate of evaporation at temperature of incandescence, its workability and high melting point (3655°K). Tungsten filaments are operated in a vacuum to prevent deterioration and to prevent conduction of heat away from the filament, allowing it to be a more efficient radiator of luminous energy.

In most design applications, the user will derate the lamp slightly to obtain maximum life while not substantially affecting the readability of the display. Published data will define the average life at rated voltage. The formula covering candle power life and current are:

$$MSCP = \left(\frac{V}{V_1}\right)^{3.4} \times \text{MSCP at design voltage}$$

$$Life = \left(\frac{V_1}{V}\right)^{12} \times \text{life at design voltage}$$

$$Current = \left(\frac{V}{V_1}\right)^{.55} \times \text{current at design voltage}$$

MSCP = mean spherical candle power
V = application voltage
V_1 = design voltage

It can be readily seen that small changes in the application voltage have a 12th power affect on life while only a 3.4 power affect on brightness. (See relationship graphically in Figure 5.1). Therein lies the main reason why direct viewed lamps can be highly reliable devices.

Since the viewer looks directly at the filament. high levels of incandescence are not required as in standard filament lamps, therefore the evaporation rate is much lower. Life of 10,000 hours minimum can be expected, at manufacturers design voltage.

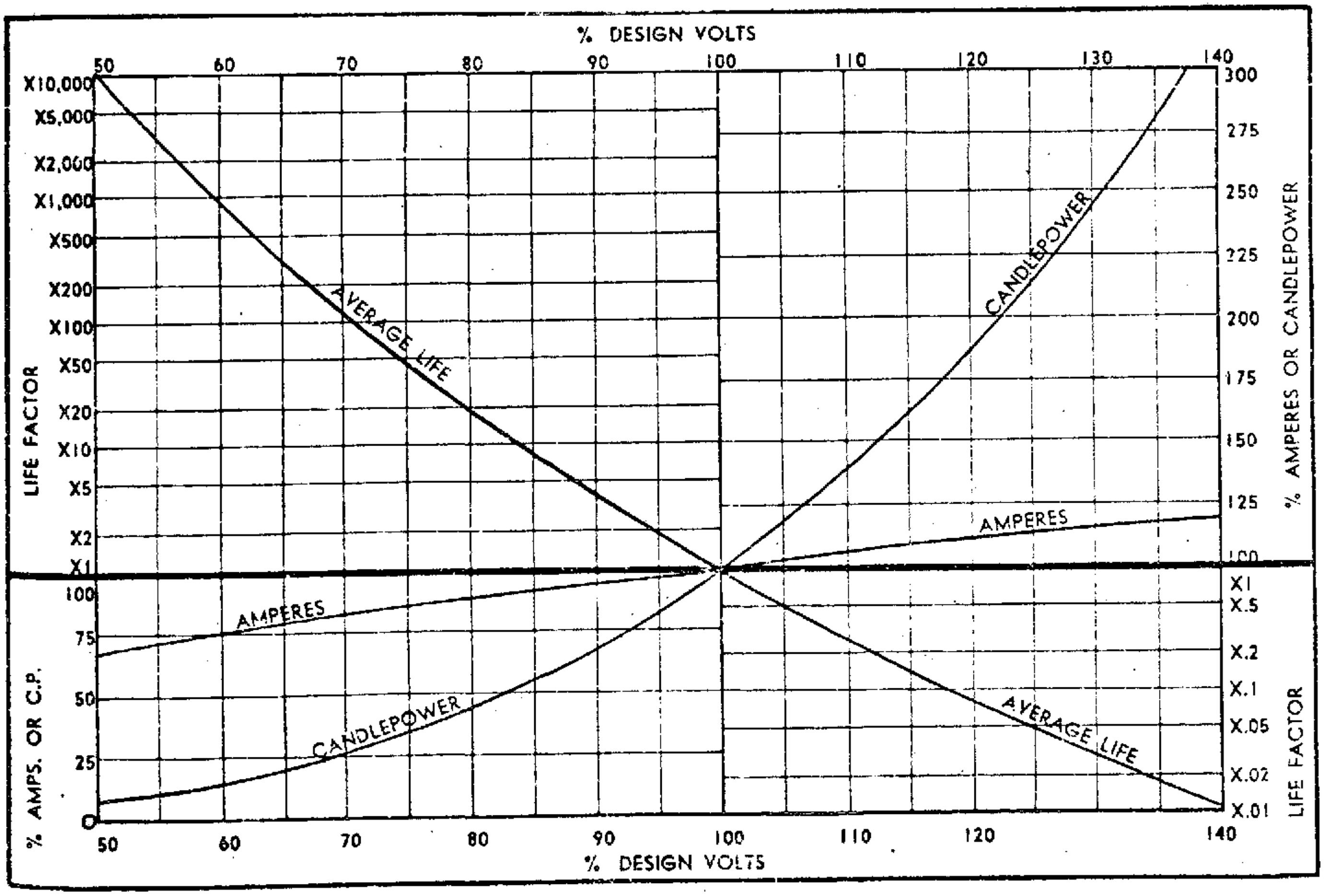
At the same time, increases of voltage beyond nominal values seriously degrades life. Therefore power supplies should be regulated to prevent overvoltages.

FIGURE 5.1

CHARACTERISTICS OF MINIATURE INCANDESCENT LAMPS

This graph relates light output, current, and life of incandescent lamps with rated (design) voltage. The curves show that the light output varies directly as the applied voltage raised to the 3.4th power, while life is inversely proportional to applied voltage raised to the 12th power.

FOR EXAMPLE:
At 110% of rated voltage, the current will increase by 5%, light output increases by 40%, and life will be reduced to nearly 35% of that at design voltage.
At 80% of rated voltage, current decreases by 10%, light output drops by more than 50%, but lamp life is increased to 18 times normal.



Operating rates of incandescents, is a function of the cooling and heating time of the filament. Normally a typical operation will be about 10 times/second, to obtain non-ambiguous characters.

Next to operating temperatures, shock and vibration are the most serious detractors from lamp life. As lamps age, the filament become embrittled due to grain growth. The longer a lamp ages the greater is its vulnerability to shock and vibration failures. Failure occurs most often in areas where there is a thermal gradient. Higher voltage lamps when compared to lower voltage lamps have characteristics which make them less reliable in shock and vibration. For a given lamp size, as the design voltage is increased there is a corresponding increase in wire length and a decrease in wire diameter. This results in more grain boundry intersections of the filament that are exposed to potential failure. Higher voltage lamps generally have lower resonant frequencies, and a greater number of resonant points which result in a greater tendency for shorting between filament segments.

As discussed previously, most available lamp displays are IC compatible. Commercial decoder drivers, converting from BCD to seven segment, are available from a multitude of manufacturers in any of several configurations as DIP's, flat packs, or T.O. cans.

INCANDESCENT READOUTS

SUMMARY OF CHARACTERISTICS

Power Requirements	0 to 5 vdc 150 to 600 mw max. Device is considered low power, low RFI generation, intrinsically safe.
Availability/Flexibility	
-Alphanumerics	Multiple digit indicators readily available from many manufacturers. Alphanumerics also available.
-Custom Arrays	Tooling costs appear to be prohibitive. Manufacturers dealing in large quantity production.
Visibility	
-Color variation	Use of filters can generate any desired color.
-Contrast	Extremely high luminesence. Some devices have intrinsically high contrast ratio but all can be brought to satisfactory levels by enhancement filters.
-Sensitivity	No sensitivity problems
-Field of View	120^{o}
-Maximum Viewing Distance	No limits - Function of character size.
-Format Variation	Fixed (alphanumeric)
Reliability	
-Life	40,000 hrs to 100,000 hrs at rated voltage
-Vibration	Specific data not available

SUMMARY OF CHARACTERISTICS - (Continued)

Economics	
-Display	Costs range from \$3.50/digit to \$25.00
-Decoder Driver	Costs/digit \$0.60 to \$1.50

5.2 Mode Annunciator

5.2.1 Description

The Mode Annunciator is a projected film message indicator utilizing a unique opto-mechanical design concept to provide a visual message, typically of modes, such as the operating modes of a vehicle flight guidance and auto-throttle system. The four channel unit, shown in Figure 5.2 , is only one inch high by 5-1/2 inches wide and 7-1/2 inches deep. It can display 128 different messages; ie, 32 per channel. The messages can be coded word descriptions such as "HDNG SEL" or any alphanumeric or pictorial information fitting on a standard 16mm frame. Single channel display units have been designed and occupy approximately 1/4 the width and volume of the 4 channel unit.

Each display channel consists of the following major components: a shaft encoder, a stepper motor, transport mechanism, film strip, fiber optic light guide, tapered fiber optic 4 x magnifier, light source assembly and diffuser as shown in Figure 5.3 . The data commanding a particular message to be displayed is supplied in the form of electrical signals generated by either a separate, remotely located logic unit, or by integral electronic cards containing the logic, drive circuitry and power supply. The signals are fed directly to the stepper motor which is mechanically slaved to a 32 position shaft encoder. The angular position of the encoder, as it follows the movements of the stepper motor is electrically monitored by the logic computer. The results are compared with the command input signals. When a null is reached between the encoder signals and the command signals the stepper motor is deactivated.

Messages are stored on a continuous loop of 16 mm metalized mylar photographic film mounted on the transport assembly. The stepper motor, activated by signals from the logic computer, indexes the desired messages on the film to the viewing position.

Light from two lamps, concentrated by reflectors, pass through the fiber optic dual light pipes into the input end of the tapered fiber bundle. The message film is channeled between the light pipe and the input end of the tapered fiber bundle. A shadow image of the message on the film is produced at the small end of the tapered fiber bundle and a 4 x magnified image appears at the larger or viewing end of the fiber bundle.

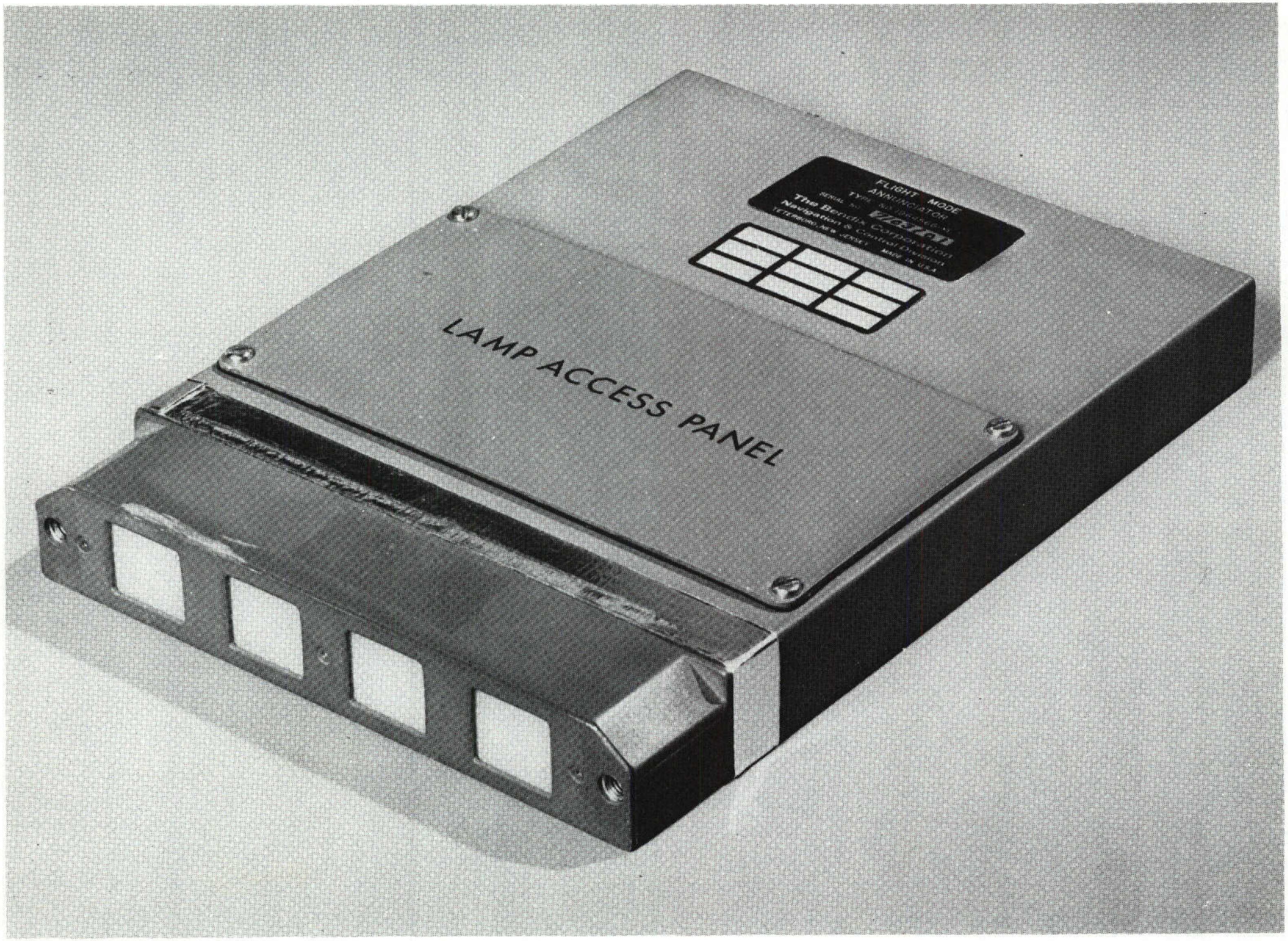

FLIGHT MODE
ANNUNCIATOR
The Bendix Corporation
Navigation & Control Division
LAMP ACCESS PANEL

FIGURE 5.2

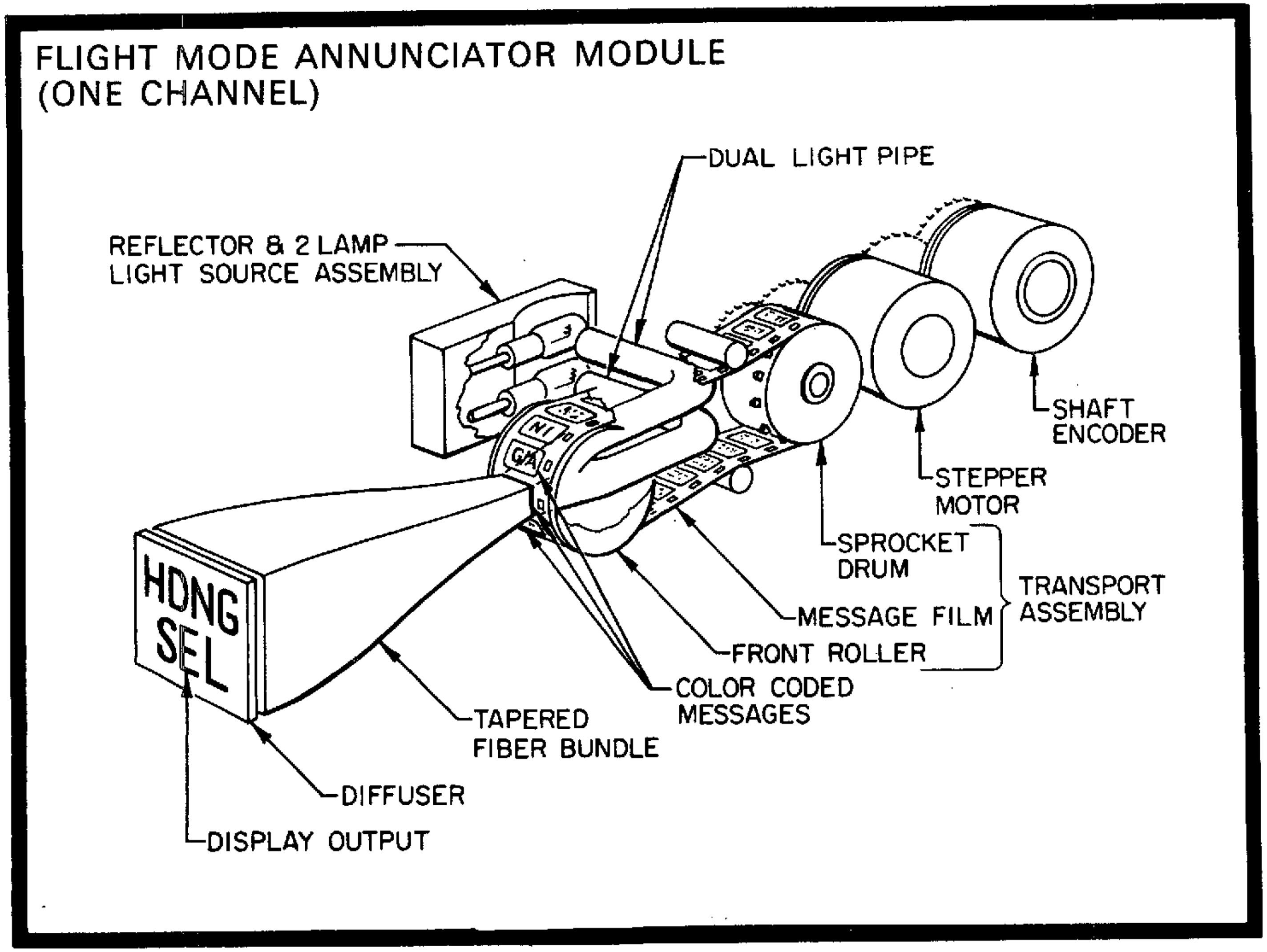

FLIGHT MODE ANNUNCIATOR MODULE
(ONE CHANNEL)
DUAL LIGHT PIPE
REFLECTOR & 2 LAMP
LIGHT SOURCE ASSEMBLY
SHAFT
ENCODER
STEPPER
MOTOR
SPROCKET
DRUM
TRANSPORT
ASSEMBLY
MESSAGE FILM
FRONT ROLLER
COLOR CODED
MESSAGES
TAPERED
FIBER BUNDLE
DIFFUSER
DISPLAY OUTPUT
HDNG
SEL

FIGURE 5.3

A diffuser at the output end of the fiber bundle provides for wide angle viewing with no visual loss of display resolution.

The fibers included in the tapered bundle have a cross sectional diameter of .001 inch on the output end. This fiber size represents a limiting display resolution of 25 line/mm, a resolution far better than the resolution limit of the eye in this application. The tapered bundle produces a magnified image with no apparent loss in display resolution.

The fiber optics additionally behave as an off-axis filter. By varying the optical properties of the fiber glass, and the diffuser, the display viewing angle can be varied. Incident ambient light exceeding the viewing angle does not traverse the bundle, and is absorbed at the walls of the fiber. As such, this ambient light,that would otherwise reduce the display contrast,does not penetrate the fiber bundle.

Display legends can appear in any size or format and in any color.

Spare bulbs are included in the indicator and are accessible through a lamp access panel located on the outside of the unit. Lamp replacement is achieveable while panel mounted and without the need for special tools.

5.2.2 Performance Specifications

Salient performance specifications are presented in Table 5.1.

5.2.3 Design Advantages

High message capacity packaged in small volume due to condensed film message magnified at output viewing end. Good brightness and viewability; low power requirements. Multi-colored displays available and complete flexibility as to legend size and configuration. Complicated symbols easily reproduced. Legend changes can be made readily by replacing film strip.

TABLE 5.1

MODE ANNUNCIATOR PERFORMANCE SPECIFICATION

Supply Voltage:	Stepper Motor Encoder Bulbs	28VDC 28 VDC 5 VDC
Power per channel		2.4 watts
Display Characters		complete flexibility same as printed word
Brightness		300 ft lamberts and variable
Field of View		160 degrees
Display Color		Multi-color coding capability
Resolution		25 line/mm
Reliability		MTBF = 20,323 hrs.
Message Capacity		32 messages/channel or more
Redundancy		Dual redundant lighting
Signal Inputs		Discrete, serial and parallel options
Weight		Single Channel, integral electronics - 1.25 lbs
Temperature		$-54^{o}C$ to $+71^{o}C$
Vibration		Tested at 2G, 5 to 500 Hz (not a limit test)
Shock		Tested at (18) shocks, 10G in 5.5 msec. (not a limit test)
Cost		$8.30 per message approx. (each message may have up to 10 digits or pictorial information)

5.3 Electro-Magnetic Digital Indicator

5.3.1 Description

Magnetic Digital Indicators are miniature, lightweight units for display of digital information. The units are ideally suited for use in panel instruments, computers, and electronic systems that require the display of numerals, symbols, and various digital codings.

The indicators consist of an encapsulated five-pole stator and a rotatable permanent-magnet rotor to which is attached an aluminum disc inscribed with numerals or other symbols, as desired. The rotor is the only moving part and rotates on jewel bearings.

Controlled excitation of the stator coils in any of the modes positions the rotor into one of ten discrete positions. The aluminum disc attached to the rotor is thus aligned with the display window to show any one of the ten symbols inscribed on the disc. With either type, excitation may be removed at any time, and a magnetic detent will keep a particular symbol in position, allowing display of information in either the energized or de-energized states. The indicators may be used singly or in multiples when more than single-digit information is required. They provide fast response time for an electromechanical indicator because sequential drive is not required.

The Magnetic Digital Indicators feature

- High reliability
- Low excitation power
- Fast response time
- Readability in high ambient light conditions
- One moving part
- No gears, cams, or tapes
- No electrical contacts or brushes
- No filaments or lamps

The indicators have undergone environmental and qualification testing as individual components and as part of displays used in aircraft.

5.3.2 Performance Specifications - Typical

Excitation - 12.0 VDC

Current - 80 ma/position

Power - .96 watts/position

No. Coils - 5

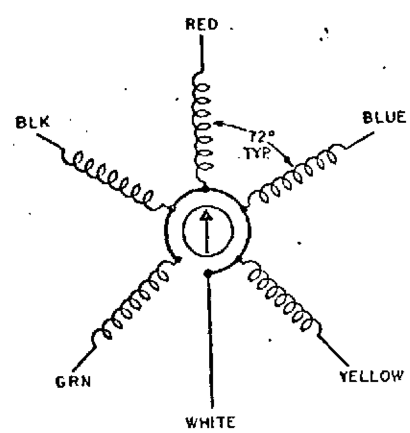
Duty Cycle - Continuous

Response Time - 200 ms (adj.pos.) - 700 ms (compl. pos.)

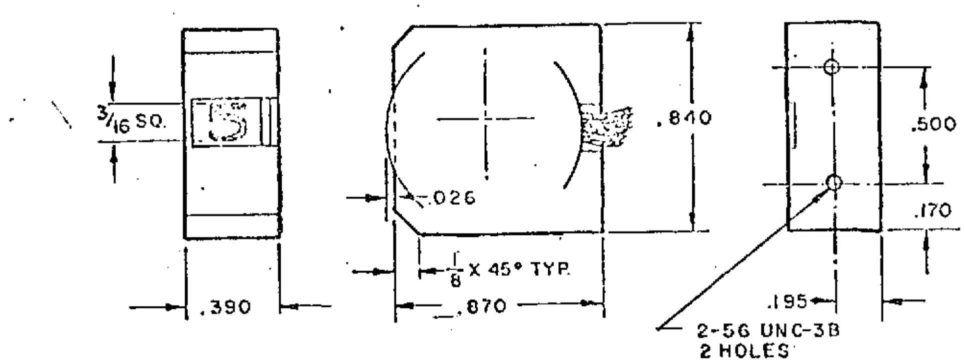
Weight - .46 oz.

Temp. Range - -55°C to +71°C

WIRING DIAGRAM



OUTLINE DRAWING



SECTION 6

CATHODE RAY TUBES

6.1 General Discussion

The Cathode Ray Tube (CRT) has served longer than any other device displaying complex dynamic pictorial, graphical, and alphanumeric information. Its versatility is seemingly unlimited. The majority of available Cathode Ray Tubes, however, are quite conventional, differing only in size or shape of envelope or type of electron gun. Because of its great versatility, the Cathode Ray Tube has found applications in data recording, scan conversion, electronic image generation, production of color displays, and projection, to name a few. As a result, special tubes have been developed with individual, unique characteristics. For example, one manufacturer, DuMont, has designed over 4000 CRT types to date. Other CRT's are presently in various states of development, Of significance in this latter category, is the flat panel digital CRT which is particularly adaptable to one of the more recent applications that of display of computer-processed information.

In the past few years dramatic advances have been made in digital MSI and LSI microcircuit technology, with the result that there has been an almost universal shift to digital display techniques. D to A, A to D, and synchro to digital converters, in building block form suitable for mounting on printed circuit boards, are now available from numerous sources in a variety of speed, resolution, and accuracy combinations. It has even become common practice to incorporate digital correction in D to A converters to compensate for such CRT/deflection yoke deficiencies as pin cushion distortion. All the attributes inherent in digital computation such as temperature insensitivity, adjustable precision, repeatability, etc. are now conveniently available for exploitation in systems requiring a visual, graphical display as an output.

Thus, it is anticipated that the conventional CRT will remain a strong contender for the multipurpose graphic, TV, alphanumeric display role in spacecraft and many other applications. The shallow, flat panel matrix CRT will have a role where depth is critical and where digitally processed graphic or alphanumeric information is to be presented. A cost penalty, however, will be entailed.

Many versions of the CRT, potentially, have application in spacecraft. Several in this category are described herein. Complete details may be obtained in the referenced source documents.

6.2 Single Gun Monochromatic CRT

The most commonly used/proposed CRT for the aircraft/spacecraft application is the single gun, electromagnetically (EM) deflected, electrostatically (ES) focused version. This tube has proven to be the least complex, most rugged, and consequently most reliable CRT in use today. The combination of EM deflection and ES focus is the result of performance tradeoffs to obtain the small spot size and reduced tube length of EM deflection and the lower power requirement of ES focus. Although EM deflection implies driving an inductive yoke, which normally requires more power then that required to obtain similar speed in an ES focused CRT, modern solid state techniques have been developed to minimize the required power.

Original color TV utilized this type CRT with a synchronized, rotating color disc to generate a full color picture. This design, however, is now considered outmoded. Typical maximum performance characteristics for this type CRT used in a panel mounted or projected display (HUD) application are as follows:

Spot size	.005" to .008" minimum
Brightness	8000 Ft.L. (at 2000"/sec, HUD application) 2000 Ft.L. (at 100,000"/sec P31, MFD application)
Write Speed	250,000"/sec (8" diagonal)
Shades of Gray	8(10,000 F.L. ambient)

6.3 Dual-deflection CRT

A modification to the basic electromagnetic type of Cathode Ray Tube has been the addition to the gun of so-called "minor-deflection" plates which are capable of only a limited area of scan; these can be used for generating symbology in screen locations selected by the major-deflection electromagnetic system. Thus, the advantages of the electromagnetic tube can still be utilized, yet symbols can be formed at the high rates possible only with electrostatic deflection.

6.4 Multigun CRT

One solution to the problem of the increasing amounts of data to be displayed has been to increase the number of electron guns in the CRT. This is necessary when either the amount of data to be displayed exceeds the capability of one gun, or time-sharing of a single gun between two data sources would cause a loss of primary data. Typical of the latter is the display of radar-derived video, with interruptions for symbology. Another typical example is the shadow mask color CRT using a triple-gun CRT with one gun for each primary color.

6.5 Optically Ported CRT

In some applications it is necessary to display a fixed format, such as a geographic map, on the screen while changing other data. By placing one or more optical ports in the rear of the tube, the fixed data may be projected onto the tube screen from slides in a projector, while computer-derived or real-time (such as radar) data are simultaneously displayed using the electron beam. The slides may be changed to permit range scaling or offsetting of the display. The ports, besides being used for projection of fixed data, can be used for filming the display if a permanent record of the displayed data is desired.

6.6 Beam-shaping CRT

One method for generation of a symbol on the CRT screen is to move the electron beam so as to describe the desired figure. A second way is to form the electron beam in a manner akin to an extrusion process. Several CRT's have been developed using this second technique. In these tubes, a stencil-like matrix, a thin disk with alphanumeric and symbolic characters etched through it, is placed in front of the electron gun. A stream of electrons emitted from the gun is deflected and extruded through the selected character of the matrix. Thus the beam is shaped, and upon reaching the phosphor screen, the extruded character is reproduced. An aperture is provided in the matrix for those applications where finely focused spots and fine lines are also required.

After the electron beam has been shaped by the matrix, it is directed back on axis by a convergence coil and reference plates. Another deflection coil is used to position the beam to the appropriate spot of the screen.

Normally, 64 characters are etched into the matrix, but where required, as many as 200 can be accommodated. Variable character size can also be obtained. Larger characters require a longer dwell time, of course, to obtain the same effective luminance.

A unique, simplified version of this CRT is the Nimo message indicator. This low cost device incorporates fixed internal deflection to provide any one of up to 64 messages on a .63" x .63" area. Each message can contain up to five lines of 8 or less characters per line.

6.7 Flat Panel Digital CRT

A recent innovation in the display field is the flat panel, digitally adressed CRT, designated the DIGISPLAY*, and developed by Northrop. It utilizes an areal electron source followed by a series of very thin, apertured plates which are aligned and act collectively to generate a scanning electron beam or beams. The positions of the beam(s) are determined by digital addressing signals applied to patterned electrodes on the control plates as shown in the cross-sectional view in Figure 6.1. By switching the plate voltages sequentially, an electron beam scanning pattern is achieved. These operational characteristics result in a flat TV/graphic or alphanumeric display configuration as shown in the Figure 6.2 where the DIGISPLAY is compared with a conventional cathode ray display tube. Inherent features include:

a. Reduced size and weight, flat panel construction - the depth is approximately two inches.

*Northrop Trademark

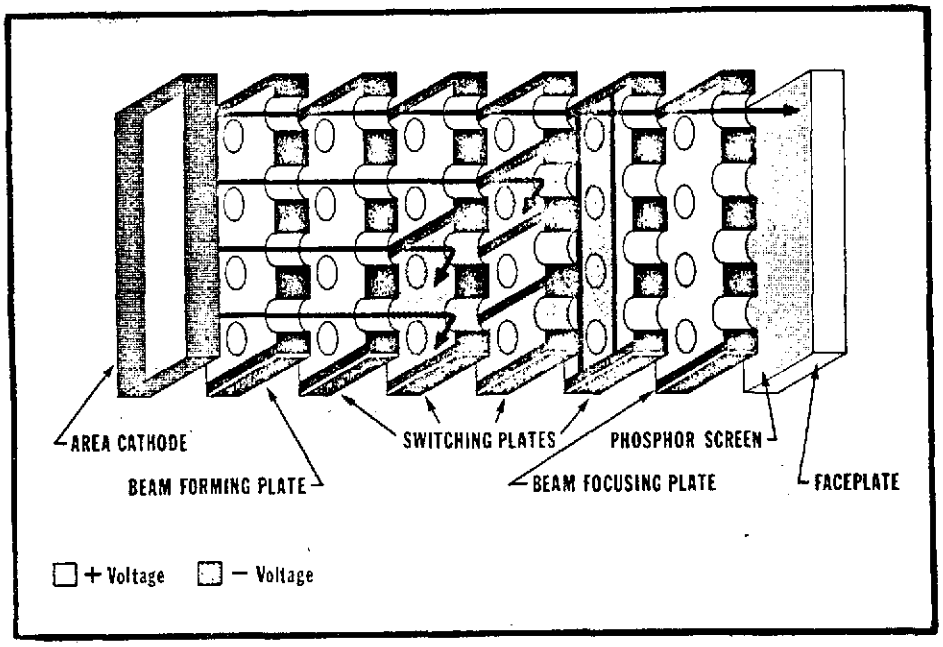


FIGURE 6.1

MULTIPLE SWITCHING PLATE ACTION

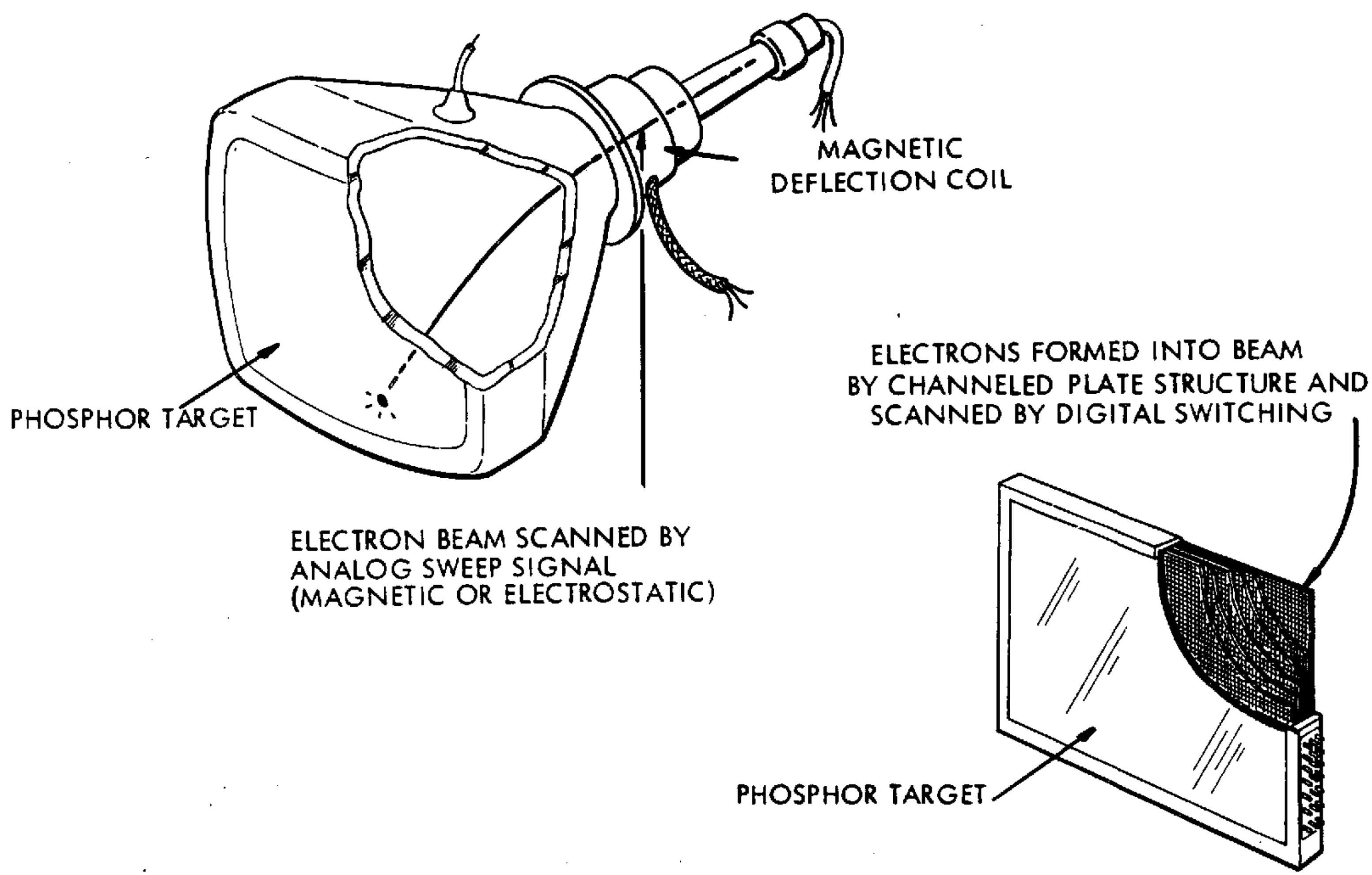


FIGURE 6.2 DIGISPLAY COMPARED WITH CONVENTIONAL ELECTRON BEAM SCANNING

b. Digital address - the digital nature of the device permits handling of input signals directly from digital equipment such as computers, data processors, magnetic recorders, data links and memory units, with a minimum of interface equipment.

c. Fixed linearity and registration - the electron beams are physically confined by accurately placed channels in the scanning control plates.

d. Multibeam scanning - simultaneously scanning multiple electron beams can be used to increase beam dwell time and thereby achieve significantly greater display brightness at reduced input power levels. The multibeam feature can also permit faster writing speeds.

e. Random scan capability - unlike the CRT, the time required to switch the beam position in the DIGISPLAY is not dependent on the distance the beam is moved. Random scan allows a reduction in frame rate without the presence of noticeable flicker.

f. Optional storage capability - an inherently simple method of providing direct view storage capability can be used to obtain substantially higher brightness levels or to prolong the viewing time of any particular information display with no refresh memory required. The storage DIGISPLAY uses only one gun to write, flood and erase, and does not require the CRT's collector mesh, ion repeller, or complex collimating system, which should result in a lower manufacturing cost.

g. Stray field independence - performance is relatively unaffected by stray electric and magnetic fields.

In addition, the flat panel display provides the means for presenting information from several data inputs simultaneously in a monochrom or multicolor display. The format can consist of a rectangular matrix of channels for an XY raster scan or an Rθ channel pattern which permits a radar type radial scan without the necessity for coordinate transformation.

6.8 Penetration Color CRT

Control of the depth of penetration of the electron beam into a series of phosphor layers to produce different colors has been used in several color tubes. Either a single gun or three separate guns may be used. Typically, the difference between penetration of the layers is 6kV/layer. In the case of separate guns, the individual guns are biased at the required voltage relative to the anode; with the single-gun unit, the anode voltage itself is switched. One of the drawbacks to the single-gun system is the low rate, approximately 50 μs, at which the anode voltage can be switched. Presently achieved rates are far short of that required for television. However, with random-display units, the switching can be programmed to take place while beam positioning is occurring. A more serious drawback is the change in deflection sensitivity associated with the varying anode voltage. Registration and accuracy become formidable problems with this type CRT when it is necessary to align different color images.

Another drawback to the development of penetration-control tubes has been the lack of transparent, high-luminance color phosphors. However, processes for making transparent phosphors have been greatly improved. Very high resolution has been claimed for the newer transparent phosphors, approaching that of monochromatic CRT's far superior than the shadow mask color CRT.

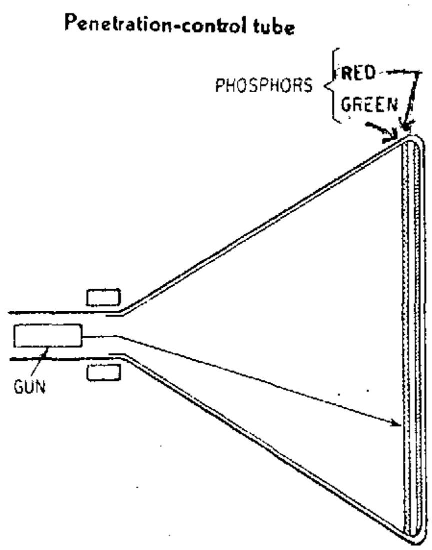


FIGURE 6.3

The range of colors obtainable is dependent upon the phosphors used and the anode voltage applied as shown in the following Chromaticity Diagram, Figure 6.5.

A general listing of standard JEDEC registered screen materials is also included in Table 6.1.

6.9 Shadow-mask Color CRT

The shadow-mask tube is an excellent example of the use of an electron gun for each phosphor. The construction of this tube is shown in Figure 6.4. The shadow mask, a thin performated electrode, is placed close to the screen and registered with it such that each hole in the mask coincides with a triad of three phosphor dots, one for each primary color. The gun alignment is such that only phosphor dots of one color can be energized by a given electron beam.

The shadow-mask principle has also been used in a single-gun color tube. Here the direction of the electron beam is controlled with a color-selection magnetic field such that the beam passes through the shadow mask to strike one of the three phosphor dots.

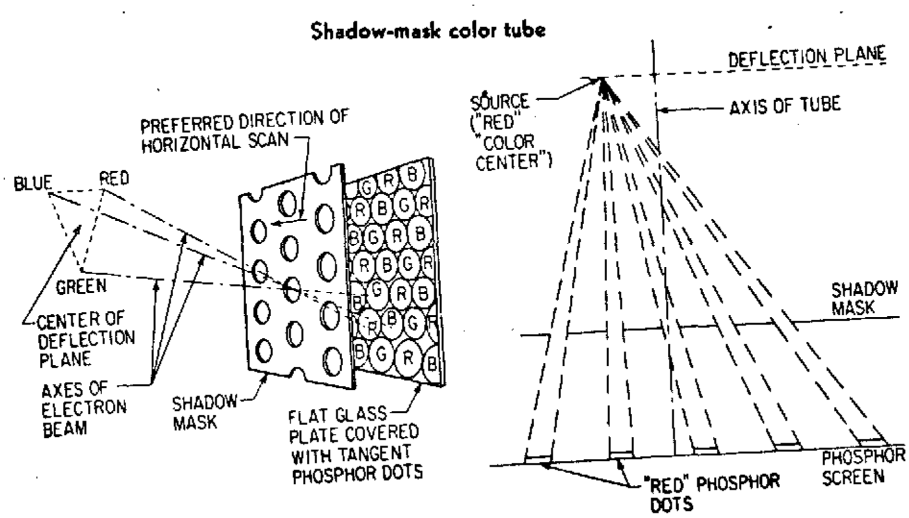
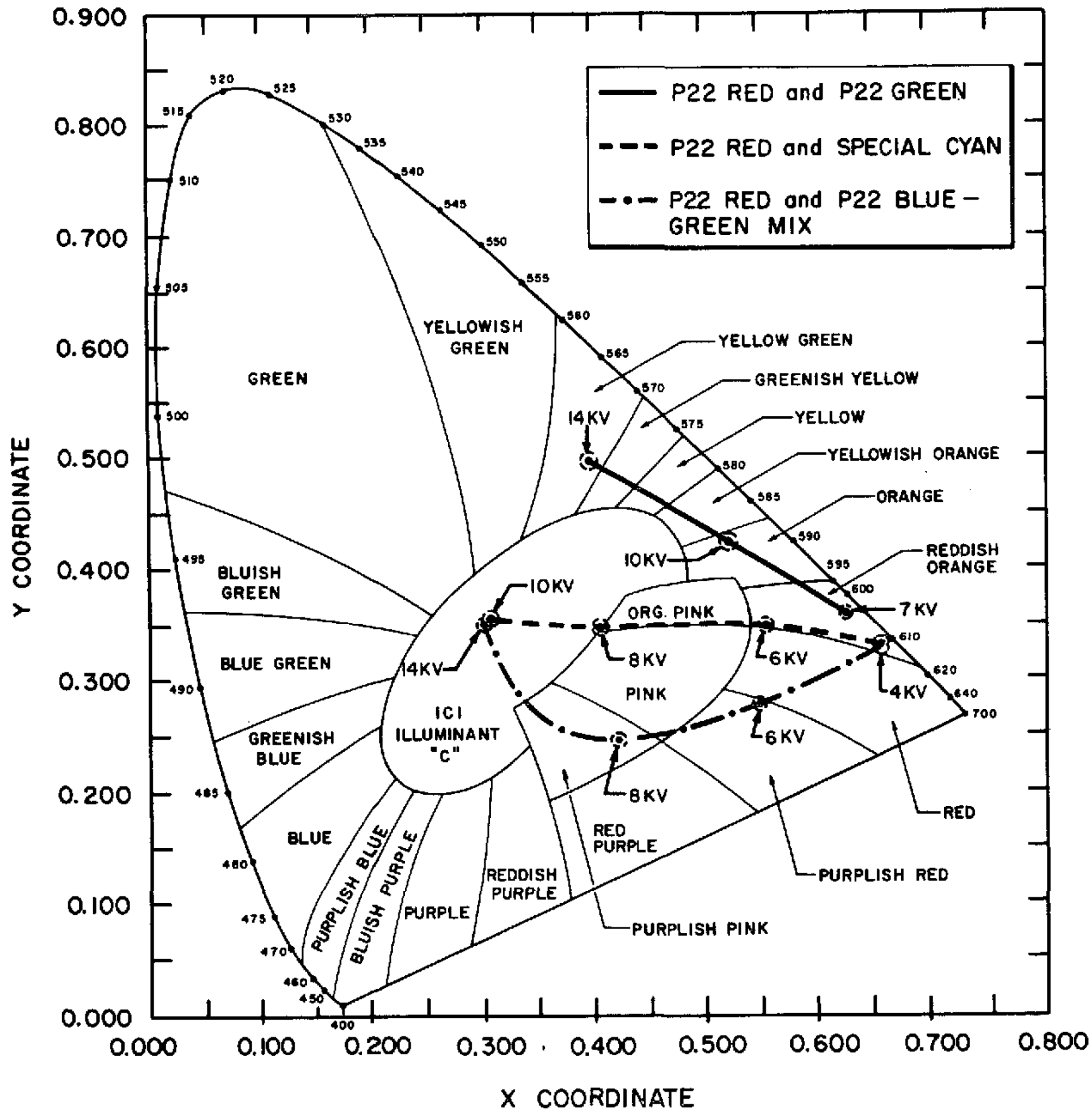


FIGURE 6.4

FIGURE 6.5
Chromaticity Diagram for Various Two-Phosphor Combinations



The CIE Diagram illustrates three examples of different phosphor combinations in a multicolor tube. The solid line curve indicates the color range of P22 Red and P22 Green Phosphor combination, obtained by operating the anode voltage between 7KV and 14KV. The dotted line curve cites an example utilizing two other primary color phosphor combinations. The dot-dash curve indicates that the color selection need not be limited to a straight line between two points, but by selection of materials and process, a greater color range may be obtained.

TABLE 6.1

PHOSPHOR SCREEN CHART

Registered Phosphor Type	Color: Fluor-escent	Color: Phosphor-escent	Persistance	General Use
P 1	YG	YG	M	Oscillography, radar, HUD
P 2	YG	YG	M	Oscillography
P 3	YO	YO	M	Proj. TV (with blue)
P 4	W	W	M-S	Direct View TV
P 4	W	W	M to MS (Sulfide Silicate Type)	Theater Proj. TV
P 5	B	B	M-S	Photographic applications
P 6	W	W	S	Direct View TV
P 7	W	Y	M-S (blue L (yellow)	Radar and Oscillograph
P 8		(replaced by P 7)		
P 9		(reservation withdrawn)		
P 10		(scotophor)		Radar
P 11	B	B	M-S	Photographic applications
P 12	O	O	L	Radar
P 13	R-O	R-O	M	Radar
P 14	P-B	YO	M-S (blue) M (yellow orange)	Radar and Oscillography
P 15	U. V. & G	G	V. S. (U. V.) S (Green)	Flying Spot Scanning and Photography
P 16	B-P	B-P	V S	Flying Spot Scanning and Photography
P 17	W	Y	S (blue) L (yellow)	Radar and Oscillography
P 18	W	W	M to M-S	Proj. TV
P 19	O	O	L	Radar
P 20	YG	YG	M to M-S	Oscillography
P 21	RO	RO	M	Radar
P 22	W	W	M-S (three phosphors) R, B & G)	Color TV
P 23	W	W	M-S	Direct View TV
P 24	G-W	G-W	S	Flying Spot Scanning
P 25	O	O	M	Radar
P 26	O	O	V L	Radar
P 27	RO	RO	M	Color TV Monitors
P 28	YG	YG	L	Radar
P 29	W	YW	M (P2 + P25)	Radar and Oscillography
P 30		(reservation withdrawn)		
P 31	G	G	M-S	Oscillography, Computer Displays
P 32	PB	YG	L	Radar
P 33	O	O	V L	Radar
P 34	BG	YG	V L	Oscillography, radar, visual information storage
P 35	B	B	M-S	Photographic applications
P 36	YG	YG	VS	Flying Spot Scanning and Photography
P 37	B	B	VS	Flying Spot Scanning and Photography
P 38	O	O	V L	Radar, Low repetition rate displays
P 39	YG	YG	L	Radar, Low repetition rate displays
P 40	W	YG	M-S (blue) L (yellow)	Radar, Low repetition rate displays

COLOR CODE

U. V – Ultra Violet
P – Purple
B – Blue
G – Green
Y – Yellow
O – Orange
R – Red
W – White

PERSISTANCE CODE

V L – Very long .... 1 sec. or over
L – Long .... 100 msec. to 1 sec.
M – Medium ...... 1 msec. to 100 msec.
M-S – Medium short 10 usec. – 1 msec.
S – Short .... 1 usec. – 10 usec.
V S – Very short ... less than 1 usec.

Although shadow-mask tubes have been found to yield satisfactory color pictures for commercial television, they do possess one serious drawback, limited luminance. Approximately 15 percent of the total beam current reaches the phosphor screen, resulting in low light output.

The tube is quite sensitive to stray magnetic fields, and therefore equipment associated with the cathode-ray tube must be periodically demagnetized. However, the shadow-mask tube has been the most commonly used color cathode-ray tube to date.

6.10 Random Access Display Comparison

A comparison has been made of the performance and mechanical characteristics of several random access displays (RAD) which may be considered as candidates for an alphanumeric and/or graphical display aboard a spacecraft. The RAD's compared include:

A* - EM, ES Monochromatic CRT

B - EM, ES Penetration Type Color CRT

C - EM Shadow Mask Color CRT

D - Plasma Display Panel - Digivue

E - Flat Panel Digital CRT - Digisplay

Ratings of 1, 2, and 3 have been assigned to indicate the relative rank of a device with regard to a specific compared parameter, 1 corresponding to the best in a particular category. To be completely objective, however, it is necessary to evaluate each type device relative to a specific set of requirements. Therefore, due to the general nature of this study and the possible subjectivity of such a comparison, no attempt has been made to weight the compared parameters.

Results of the comparison are shown in Table 6.2 and a discussion of the parameters follows.

*Alphabetic designations have been assigned to each type RAD to simplify referencing in the parameter discussion section.

TABLE 6.2

COMPARISON SUMMARY OF RANDOM ACCESS DISPLAY DEVICES

	EM,ES Mono-chrome CRT (A)	EM,ES Pene-tration CRT (B)	EM Shadow Mask CRT (C)	Digivue (D)	Digisplay *3 (E)
Resolution	1	1	3	2	2
Brightness	1	2	2	3	1
Contrast	1	2	2	3	1
Accuracy	2	2	3	1	1
Symbol Registration	1	3	2	1	1
Size	2	3	3	1	1
Weight	2	3	3	1	1
Cost	1	2	3	3	3
Color Range	3*2	2	1	3*4	2*1
Writing Speed	2	2	3	1	1
Digital Interfacing	2	2	3	1	1
Voltage Levels	2	2	3	1	2
Reliability	1	1	3	2	2
TV Capability	1	2	1	3*5	3*5
Rear Projection Capability	2	2	NA	1	NA

*1 Potentially same color capability as penetration or shadow mask CRT.
*2 Color function of phosphor used.
*3 Random access version assumed.
*4 Orange only.
*5 TV capability requires development of high speed digital sweep and video techniques.

1) Resolution

A, B	Positional resolution essentially infinite limited only by phosphor granularity. Visual resolution limited by spot size.
C, D, E	Resolution limited by tricolor phosphor dot spacing (C), grid line spacing (D-60 per inch max.), and hold spacing (E-80 per inch max.)

2) Brightness

A, E	Both capable of generating equivalently bright displays (8000-10000 Ft.L.) limited by the burn characteristics of the phosphor.
B, C	Brightness characteristics of color CRT phosphors considerably below high brightness types.
D	Up to 50 Ft.L.

A - EM, ES Monochromatic CRT
B - EM, ES Penetration Type Color CRT
C - EM Shadow Mask Color CRT
D - Plasma Display Panel - Digivue
E - Flat Panel Digital CRT - Digisplay

3) Contrast

A, B, C, D, E	Contrast essentially related to brightness range capability. Therefore A and E brightest.

4) Accuracy

D, E	Accuracy a function of precision mechanical masks only.
A, B, C	Accuracy a function electron gun alignment, faceplate curvature, deflection system performance, correction circuits, high voltage stability. When accuracy is with reference to an independent system such as an overlay, project map, or superimposed real world, each of the above error sources is applicable. Symbol to symbol accuracy is not as severe a problem.

A	-	EM, ES Monochromatic CRT
B	-	EM, ES Penetration Type Color CRT
C	-	EM Shadow Mask Color CRT
D	-	Plasma Display Panel - Digivue
E	-	Flat Panel Digital CRT - Digisplay

5) Symbol Registration

A, D, E	Being independent of the accuracy symbol registration is not a problem.
C	Rated lower due to the addition guns and lower resolution.
B	Deflection sensitivity variation for variable color images results in a relatively more difficult symbol to symbol registration problem.

6) Size

D, E	Both considered approximately equivalent in size although HV power supply required by E.
A, B, C	CRT depth greater and deflection system required. Additional circuitry required to handle switched power supply and deflection gain change for B and three video channels of C.

A	-	EM, ES Monochromatic CRT
B	-	EM, ES Penetration Type Color CRT
C	-	EM Shadow Mask Color CRT
D	-	Plasma Display Panel - Digivue
E	-	Flat Panel Digital CRT - Digisplay

7. Weight

A, B, C, D, E Weight essentially proportional to size.

8. Cost

Rankings are based primarily upon the known and estimated cost of the particular devices. A more thorough analysis, considering auxillary circuits and a specific application, is necessary to determine comparative system cost.

A	-	EM, ES Monochromatic CRT
B	-	EM, ES Penetration Type Color CRT
C	-	EM Shadow Mask Color CRT
D	-	Plasma Display Panel - Digivue
E	-	Flat Panel Digital CRT - Digisplay

9) Color Range

C	Provides full color range although at reduced brightness.
B	Normally limited to two colors, red and green, and shades between.
E	Penetration color versions of this device have been built, and it is theoretically possible to build a tricolor dot version having the color range capabilities of C.
A	Phosphor type determine color.
D	Gas used determines color.

10) Write Speed

D, E	No deflection system required, therefore, no slew delays normally characteristic of deflection yoke/driver stages. Max. speed a function of propagation times and/or computer cycle time.
A, B, C	Upper limit a function of deflection system slew speed which is directly related to deflection system size and power. The normal higher ultor voltage of C results in stiffer electron beams and corresponding higher deflection power.

A - EM, ES Monochromatic CRT
B - EM, ES Penetration Type Color CRT
C - EM Shadow Mask Color CRT
D - Plasma Display Panel - Digivue
E - Flat Panel Digital CRT - Digisplay

11) Digital Interfacing

D, E	These flat panel units are digital "on-off" devices by nature and therefore are more simple to interface.
A, B, C	All three are analog devices requiring D to A converstion to drive the deflection system from a digital computer C requires additional circuitry to drive the three video channels.

A	-	EM, ES Monochromatic CRT
B	-	EM, ES Penetration Type Color CRT
C	-	EM Shadow Mask Color CRT
D	-	Plasma Display Panel - Digivue
E	-	Flat Panel Digital CRT - Digisplay

12) Voltage Levels

D	This type unit is a low voltage device requiring a max. DC of approximately 100 V. Thus it is safer when considering servicing, exposure to explosive atmosphere, and arcing problems.
A, B, C, E	These units require the higher voltages typical of CRT devices. C normally requires a higher ultor voltage.

13) Reliability

A, B	These two CRT's are the least complex devices and are, therefore, inherently more reliable.
D, E	The flat panel devices are more complex internally, and are therefore, inherently less reliable considering the probability of failure and not the effect. However, they are far less subject to catastrophic failures.

A	-	EM, ES Monochromatic CRT
B	-	EM, ES Penetration Type Color CRT
C	-	EM Shadow Mask Color CRT
D	-	Plasma Display Panel - Digivue
E	-	Flat Panel Digital CRT - Digisplay

14) TV Capability

A, B, C	All three devices are readily adaptable to TV raster displays.
D, E	The flat panel units require the development of high speed, digital sweep and video circuits which appear only to be practical using LSI techniques.

15) Rear Projection Capability

D	This unit is readily adaptable to rear projection in its basic form.
A, B	Using a special bulb design with optical port, these units are adaptable to rear projection.
C, E	No rear projection capability due to the internal obstruction created by the plates, ie. shadow mask (c) switching plates (E).

A	-	EM, ES Monochromatic CRT
B	-	EM, ES Penetration Type Color CRT
C	-	EM Shadow Mask Color CRT
D	-	Plasma Display Panel - Digivue
E	-	Flat Panel Digital CRT - Digisplay

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